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Evaluation of En Route Host Computer System's Tactical Alert Processing:

Description of Methodology

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16. Abstract

The technical note is the third in a series of metric reports related to the En Route Automation Modernization Program's Surveillance Data Processing Function. This study's focus is on the performance of the tactical conflict alert function. Comprehensive metrics are developed that quantify the missed and nuisance detections of the tactical conflict probe. The study implemented a series of simulations developed in the Integration and Interoperability Facility (IIF) at the William J. Hughes Technical Center. The simulations were applied to the legacy Host Computer System and tactical conflict alerts it produced. This technical note documents the processing involved in application of the developed metrics on the legacy Host Computer System. It includes an annotated flowchart of the processing in the tools developed and application on a few flights. A subsequent companion report will provide a detailed discussion of the results using thousands of flights from the simulations in the IIF.

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Executive Summary

The FAA's ERAM Test Group formed the Automation Metrics Test Working Group (AMTWG) in 2004. The team's charter is to support the developmental and operational testing of ERAM by developing a set of metrics that quantify the effectiveness of key system functions in ERAM. The targeted system functions are Surveillance Data Processing (SDP), Flight Data Processing (FDP), Conflict Probe Tool (CPT), and the Display System (DS) modules. The metrics are designed to measure the performance of ERAM. They also are designed to measure the performance of the legacy En Route automation systems in operation today. When appropriate, they will allow comparison of similar functionality in ERAM to legacy systems.

The project is divided into key phases: first a metrics identification process was performed. A list of approximately one hundred metrics was generated by the AMTWG and mapped to the Air Traffic services and capabilities found in the Blueprint for the National Airspace System Modernization 2002 Update. This took place most of fiscal year 2004 and initial metrics results were published in June 2004 in the document titled, "ERAM Automation Metrics Progress Report of the Automation Metrics Test Working Group". Next, an implementation-planning phase was performed. In this step, the identified metrics were prioritized for more detailed refinement during 2005. The plan "ERAM Automation Metrics and Preliminary Test Implementation Plan," documents the implementation-planning phase. It lists these metrics, gives the rational for selecting them, and provides a high level description on how the highest priority metrics will be measured.

The final project phase is the data collection and analysis phase. In this step, AMTWG will document the further refinement and application of these metrics on the current legacy systems in a series of Metric Reports. AMTWG is planning the delivery of four Metric Reports for fiscal year 2005 covering several of the ERAM subsystems.

The current technical note is the third in a series of metric reports related to the ERAM's SDP function. The focus here is on the performance of the tactical conflict alert function. This study develops detailed metrics to quantify the missed and nuisance detections of this tactical conflict probe. The study implemented a series of simulations developed in the Integration and Interoperability Facility. They were then applied to the legacy Host Computer System and tactical conflict alerts recorded. This technical note documents the processing involved in application of the developed metrics on the legacy Host Computer System. It includes an annotated flowchart of the processing in the tools developed and application on a few flights. A subsequent companion report will provide a detailed discussion of the results using thousands of flights from the simulations in the IIF.

The objective is to develop statistics that provide a baseline of performance for the legacy Host tactical conflict probe that can later be referred to in the ERAM Testing Program for similar SDP functionality. This study like its predecessors provide a strong foundation to address the critical operational issue (COI 1.0), as documented in the FAA's *Test Evaluation Master Plan* for ERAM. COI 1.0 requires the ERAM Test Program to verify that ERAM supports air traffic control operations with at least the same effectiveness as the current system. Furthermore, the tools and metrics developed can be used to verify the accuracy of the tools being used by the development contractor for the formal testing of SDP.

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1 Introduction

1.1 Purpose

The Federal Aviation Administration (FAA) is developing a new Air Traffic Control (ATC) system to replace the existing Host Computer System (HCS) in the en route domain. The Host system is used by all twenty en route ATC Centers in the continental United States. The new system, called ERAM (for En Route Automation Modernization), is being developed by the Lockheed Martin Corporation. As documented in the FAA's *Test Evaluation Master Plan*, the ERAM Test Program is required to ensure key operational issues are verified (WJHTC/ACB-550 2003). These issues are organized as "Critical Operational Issues" (COI's). The first critical operational issue (COI 1.0) requires that ERAM supports ATC operations with at least the same effectiveness as the current system. Therefore, the performance of the radar track subsystem in ERAM must be as good as the performance of the existing Host radar tracking. To determine this, a baseline performance of the Host is required to provide performance standards to later compare to ERAM.

This technical note documents the processing involved in measuring the performance of the Host Computer System (HCS) prediction of tactical aircraft-to-aircraft conflicts. A conflict is the loss of the minimum required aircraft separation which in en route airspace is five nautical miles and 1000 feet vertically.

This study is one of several being conducted by the Automation Metrics Test Working Group (AMTWG). The studies are described in the "ERAM Automation Metrics and Preliminary Test Implementation Plan," published in June 2005 (WJHTC/ACB-330 2005).

This technical note is the first of a pair of reports. The first report describes the methodology used to measure the performance of the Host radar tracking function and the second report gives the results of applying the methodology.

1.2 Background

The FAA's ERAM Test Group formed the Automation Metrics Test Working Group (AMTWG) in August 2003. The team's charter is to support the developmental and operational testing of ERAM by developing a set of metrics that quantify the effectiveness of key system functions in ERAM. The targeted system functions are Surveillance Data Processing (SDP), Flight Data Processing (FDP), Conflict Probe Tool (CPT), and the Display System (DS) modules. The metrics are designed to measure the performance of ERAM. They also are designed to measure the performance of the legacy En Route automation systems in operation today. Many of the metrics will allow comparison of the functionality in ERAM to similar functionality in the HCS and URET (User Request Evaluation Tool) legacy systems.

The project was divided into key phases: first a metrics identification process was performed. A list of approximately one hundred metrics was generated by the AMTWG and mapped to the Air Traffic services and capabilities found in the Blueprint for the National Airspace System Modernization 2002 Update (FAA 2002). This took place most of Fiscal Year 2004 and initial metrics results were published in June 2004 in the document, "ERAM Automation Metrics Progress Report of the Automation Metrics Test Working Group" (WJHTC/ACB-550 2004). Next, an implementation-planning phase was performed. In this step, the identified metrics were prioritized for more detailed refinement during 2006.

The report "ERAM Automation Metrics and Preliminary Test Implementation Plan," documents the implementation-planning phase. It lists these metrics, gives the rational for selecting them, and provides a high level description on how the highest priority metrics will be measured. The Implementation Plan provides the metric's traceability to the basic controller decisions, ERAM Critical Operational Issues (COIs), and the development contractor's Technical Performance Measurements (TPMs). The categories of high priority metrics are: (1) SDP radar tracking, (2) SDP tactical alert processing, (3) FDP flight plan route expansion, (4) FDP aircraft trajectory generation, (5) CPT strategic aircraft-to-aircraft conflict prediction, (6) CPT aircraft-to-airspace conflict prediction, (7) additional system level metrics, and (8) DS human factor and performance metrics.

Currently the AMTWG is analyzing the performance of different aspects of the FAA's en route air traffic control system. The AMTWG is refining and then applying the previously defined metrics to the legacy systems. This work is being documented in a series of Metric Reports. four areas of metric reports are planned; one covering each of the ERAM modules discussed above, SDP, FDP, CPT, and DS. These reports are being published in multiple drops to provide the ERAM Test Team on-time information. The drops coincide with the approaches used to implement the metrics.

This technical note is the third in a series which document metrics for the SDP functions. It documents the processing of accuracy of the HCS in predicting aircraft to aircraft conflicts. This study is similar to one performed previously on the accuracy of the User Request Evaluation Tool (URET) to predict strategic aircraft-to-aircraft conflicts (Cale, et. al, 1998).

1.3 Scope

A representative sample of en route air traffic was processed by the Host and the Host's tactical conflict alert performance measured. The sample or scenario of en route air traffic was recorded in March 2005 at the Washington ARTCC (ZDC). It contains approximately four hours of flight data and 1500 flights. The flight times were adjusted to create conflicts to be processed. This adjustment procedure is described in detail in (Paglione-1, et. al, 2003). Approximately 100 conflicts were induced in the scenario above Flight Level 180. The performance of the Host is based on its ability to accurately predict these conflicts.

The ERAM A-Level requirements specify that all tactical conflict alerts be presented with a minimum warning time of 75 seconds and a maximum warning time of 135 seconds. This translates to a zero missed alert rate. The companion requirement specifies that the nuisance or false alarm rate remain at or below six percent. The details of how these requirements are measured are still being flushed out between the FAA and the development contractor. This study may provide additional insights into how this can be accomplished.

The evaluation scenario was processed by the HCS at the Integration and Interoperability Facility (IIF) at the William J. Hughes Technical Center (WJHTC). The data was collected and analyzed by computer software tools developed by the Simulation and Analysis Group at the WJHTC. The scope of this report is to describe the methodology employed in the study. The subsequent companion report will document the results.

1.4 Document organization

This technical note is organized into the following primary sections. Section 2 provides a brief overview on how the experiment was constructed. Section 3 describes the analysis procedures and metrics developed. Section 4 provides a summary and conclusions.

2 Simulation Experiment

To establish a baseline of performance, the FAA used recorded radar and air traffic control messages to evaluate the current legacy HCS tracker. A set of simulation experiments were run in the IIF Laboratory using a scenario derived from field data originally recorded by ZDC. The alerts generated by the HCS in the IIF were then evaluated against the "true" conflicts calculated from the input traffic scenario played by the simulator into the HCS.

2.1 Generation of the Evaluation Scenario

Essentially the same tools and methodology to generate the evaluation scenario were applied as previously defined in the report (Paglione, et.al, 2005). In this previous study, metrics were developed and applied to study the HCS tracker accuracy. For the current study, these same techniques have been applied to generate and validate the scenario. However, for the current study the aircraft in the scenario have been shifted in time to induce aircraft-to-aircraft conflicts and thus exercise the HCS's tactical alert processing.

2.1.1 Source Recorded Data

The live en route radar data and the message traffic were recorded on the HCS at ZDC using the Host System Analysis Recording (SAR) and Online Radar Recording (ORR) capabilities. The data was recorded on March 17, 2005. The recording lasts for about four hours including the afternoon rush and has approximately 2500 flights.

The recorded radar data was processed at the WJHTC IIF to extract the radar track data and the control messages such as flight plans and flight plan amendments.

2.1.2 Simulation Process

The scenario was fed from the Graphical Simulation Generation Tool (GSGT) into the IIF HCS. The GSGT was used to create a Looped Simulation Drive System Replacement (SDRR) simulation containing the radar, interfacility messages, and a Host Direct Sim tape containing the keyboard and other system messages. The SDRR was used to send the data over serial lines to the En Route Communication Gateway (ECG) in the same manner that data comes over telephone lines and modems into the operational ARTCCs. The radar and ATC messages were then processed by the HCS.

Two simulations were performed in this study. The first used a procedure identical to the one implemented in the previous study (Paglione, et. al, 2005) using the GSGT, which sampled the recorded HCS track reports to simulate the radar targets for the aircraft. This simulation is referred to as the GSGT Simulation Run. The second simulation also utilized the GSGT for non-radar messages but used field recordings for the radar target messages. The radar field recordings were captured by the Enroute Radar Intelligent Tool (E-RIT) system. This simulation is referred to as the GSGT/E-RIT Simulation Run. E-RIT is the FAA's Personal Computer (PC) based continuous radar data recorder, designed to provide operational multi-sensor sites with PC based radar data recording and analysis tools.

Both simulations utilized the same ZDC HCS SAR data as described above and both time shifted the flights to induce conflicts. The time shifting will be described further in Section 2.1.3. For the GSGT generated radar scenario, the radar targets are recorded without noise for determination of the true conflict events, but for fidelity in the simulation the radar noise is added by GSGT.

The radar noise is Gaussian and has a zero mean and a standard deviation of 2 ACPs. For the E-RIT recorded radar targets, no noise is added, since the original radar inaccuracies are retained by the simulation and the only changes made for the simulation are the time shifts per flight. The use of recorded, albeit time shifted, traffic data ensures a realistic evaluation scenario because the resulting traffic scenario is very similar, but not necessarily identical to, the actual traffic occurring at the time and date of the recording. Whether the generation of the radar targets is simulated or replayed from original recordings, the resulting traffic scenario is run through the HCS in the IIF Laboratory and tactical alerts recorded for the analysis.

2.1.3 Creation of Conflict Events

A sample of real air traffic recorded after intervention by Controllers has very few if any conflicts to be used as test data. The flight times in the data recorded at ZDC were shifted by the tools of the Simulation and Analysis Group to produce conflicts using a method described in (Paglione, et.al, 2003). The process used to induce the conflicts within the simulation attempts to generate a set of conflicts and non-conflict events (referred to as encounters) with certain characteristics or properties. Some of the properties considered include the minimum horizontal separation during the conflict or encounter, minimum vertical separation, encounter angle in degrees, and vertical phase of flight of the aircraft pair (i.e. level-level, level-transitioning, or transitioning-transitioning).

More details of the specific conflict and encounter properties generated for the simulations will be provided in a subsequent report desribing the results of the study.

2.2 Data Collection

The flight plans and track position reports output from the simulation HCS were recorded from the Host Air Traffic Management Data Distribution System (HADDS) in the Common Message Format (CMS) (FAA, 2001). The HCS tactical alerts were captured in the CMS output data by using a customized the General Information (GH) message adapted by IIF Laboratory personnel. All IIF HCS SAR tapes were archived as well, but the CMS formed the main output source for the simulation. The GH messages were parsed for the tactical conflict alerts and other messages used to validate the simulation.

2.3 Simulation Validation

The simulation experiment utilized GSGT to generate the both non-radar and radar messages and E-RIT recorded radar messages for one of the simulation runs. Like all simulations, the modeling approximations and message timing issues can negatively degrade the simulation and in turn render the analysis of tactical conflict alerts erroneous. Therefore, some validation exercises were performed to quantify the deviations from the GSGT generated targets and output IIF HCS track positions to the original operational HCS position reports. This was also done for the GSGT/E-RIT derived simulation run. The validation exercise provided metrics on how close each flight's track reports were from the simulated run compared to the same flight's tracks recorded from the operational HCS. Details will be given in the pending result report.

3 Procedures and Metrics

The simulation input is a set of aircraft positions, based originally from field recordings of actual aircraft tracks and air traffic control clearances, which have induced conflicts, and the simulation output is a set of tactical conflict alerts from the HCS. The analysis is a matching of the conflicts from the aircraft position reports to the alerts generated by the HCS. Various procedures are used to process the data and generate the particular metrics used to evaluate the alerts.

The basic performance metric for the tactical conflict alert function is whether or not a correct alert was presented to the Controller in a timely manner. The determination of the performance is more complicated than this simple count because there are special cases that must be accounted for. There are two classes of special cases. An alert may not have been presented properly when there was a conflict but, because of extenuating circumstances, this missed alert failure may not be counted. On the other hand an alert may have been posted when there was no conflict, but an immenent conflict would have occurred had not the aircraft been deviated by ATC. Similarly this false alert may not be counted as a nuisance alert.

For example, suppose an altitude clearance of a climbing aircraft is removed immediately before (say 20 seconds before) the start of the conflict. This removal of the altitude restriction caused the conflict. It is not reasonable to require the HCS (or its replacement, ERAM) to predict past an unforeseen event such as the removal of the altitude clearance. Therefore, the alert is still required but the warning time is reduced to match the time of removal of the clearance.

There is a set of counting rules for all of the special circumstances that may occur. They are explained later in this section.

3.1 Analysis of the Input Data

The input data consists of aircraft position reports, flight plans, flight plan amendments, and interim altitude clearances, including their posting and removal. For tactical alert processing, the HCS does not use the lateral (route) information of the Flight Plan, only the vertical clearance data.

3.1.1 Determination of Conflicts and Encounters

Ground truth position reports are used to calculate the truth conflicts. In this study as was done in (Paglione-2, et. al, 2003), conflicts are defined as violations of standard separation distances, while encounters are situations where the aircraft pairs are separated at larger distances. Since January 2005, all of continental Unitied States uses the Reduced Vertical Separation Minima (RVSM) above Flight Level (FL) 290. The minimum vertical separation has been reduced from 2000 feet to 1000 feet and only aircraft certified for RVSM operations are permitted to fly above FL 290. Consequently controlled airspace from FL 180 to FL 600 has a minimum vertical separation of 1000 feet. In this en route airspace, aircraft must be simultaneously separated by less than five nautical miles horizontally and by less than 1000 feet vertically to be considered conflicts by air traffic control.

In general, Equation 1 provides the number of pairwise combinations of aircraft in the scenario that potentially are in conflict.

$$\frac{[(n-1)n]}{2} \qquad \textbf{Equation 1}$$

where *n* is number of aircraft in the traffic sample.

An encounter is a close approach of two aircraft which is not close enough to be called a conflict. How close is close enough to be called an encounter is up to the consensus of the experimenters. Typical separations used are 7.5 nautical miles and 2500 feet. With these parameters, an encounter occurs if at any point in the flight paths of the two aircraft, the horizontal separation is between 5 and 7.5 nm and simultaneously the vertical separation is less than 2500 feet. The set of aircraft to aircraft encounters is used for analysis of the false alert performance

To simplify the processing of calculating the separation distances above, the position reports are linearly interpolated to specified time intervals (10 seconds has been used in this study) and synchronized with the hour of the day. By time synchronizing the track in this preprocessing step, the positions can be checked directly for time overlap and compared spatially. Although rare, there may be situations where the position reports retain time gaps. Rules for handling these time gaps for processing conflicts and encounters will be discussed in Section 3.2. Subsequent conflict prediction processing will need to consider these gaps as well. For example, if a conflict is predicted to occur during a time gap, it may be considered false incorrectly. Thus, these situations need to be taken into account for accurate analysis.

Figure 1 illustrates the processing to determine the conflicts and encounters. Each aircraft pair combination is compared first with a set of time and spatial filters. A gross filter serves to eliminate some of the aircraft pair combinations for a more computationally demanding fine filter, which requires comparing individual position reports in search of conflict events.

To summarize, the time overlap of the aircraft pair is calculated first. If the aircraft do not have time overlap, no further processing of the particular aircraft pair is required and the next pair of aircraft is selected. For the time overlapping aircraft, the flights are compared spatially in each dimension (i.e. ARTCC stereographic X and Y and altitude Z). If the minimum aircraft pair separation is larger than a maximum threshold horizontally or vertically (listed in Table 1), the pair is eliminated and the next aircraft pair is selected for processing. The aircraft pair combinations that have passed these gross filters are sent to a fine filter. The fine filter compares each subject aircraft position report to the time coincident object aircraft position. All aircraft pairs that pass the gross filter are sent to the fine filter at minimum get one entry in the aircraft minimum separation database table. All of the conflicts found are stored in a conflict database table and all of the encounters found are stored in an encounter database table. Therefore, all aircraft pairs that pass the gross filters have recorded information for their aircraft-to-aircraft conflict, encounter, or minimum separation events. Any aircraft pairs not passing the gross filter are discarded.

Note that a given aircraft pair may have several encounters and may have several conflicts. Every conflict is embedded inside an encounter. An encounter may have several embedded conflicts or none. If a conflict starts immediately after the end of another conflict between the same pair of aircraft, the two conflicts are combined into a single conflict. Immediately is defined by a parameter time. This study used 40 seconds (listed in Table 1). Also, very short conflicts are assumed to be a result of noisey positional data and eliminated. The duration threshold as listed in Table 1 is 6 seconds. In practice, this requires a conflict to be determined on two or more position reports (i.e. one position report conflicts are eliminated).

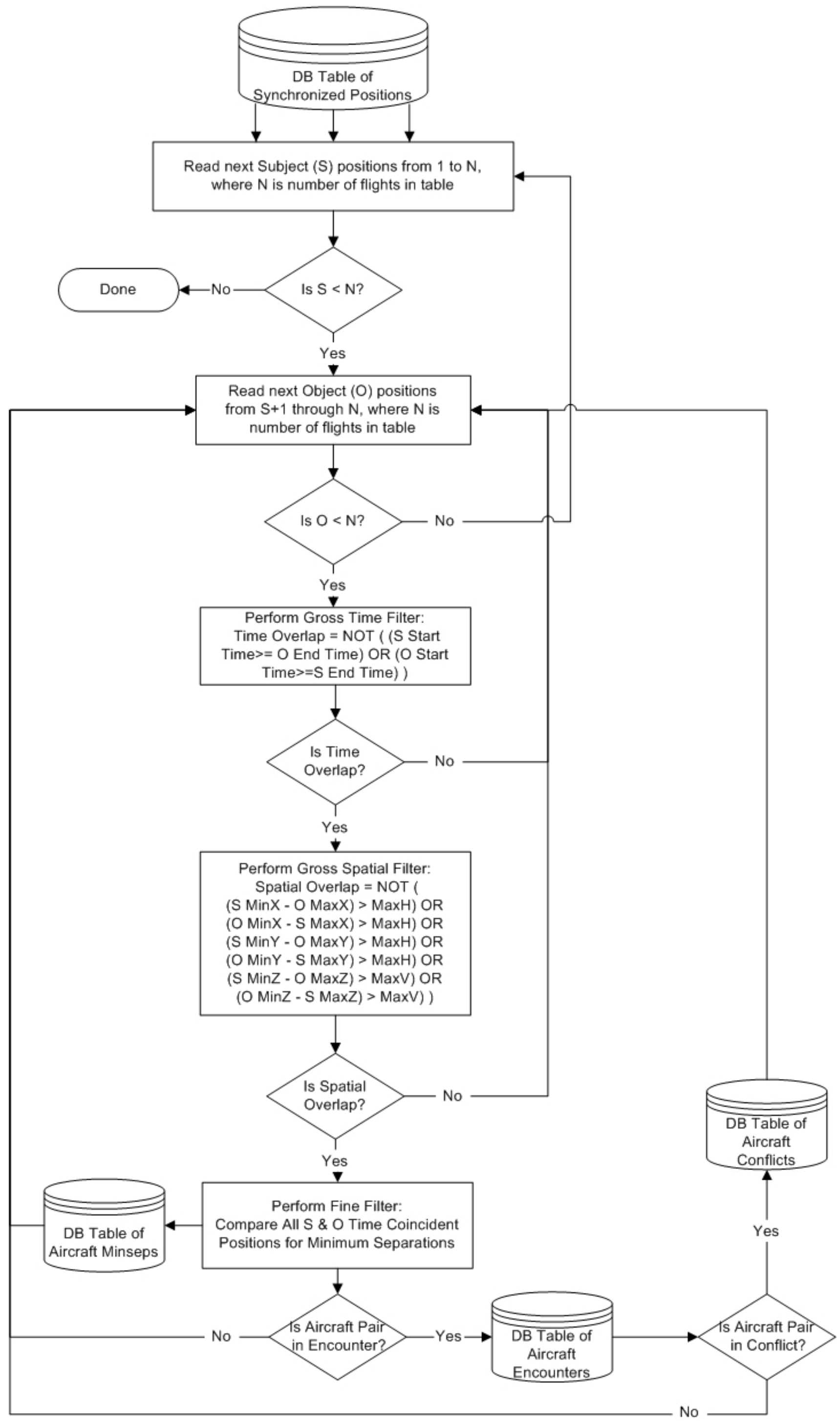

Figure 1: Calculation of Truth Conflict/Encounter Events

3.1.2 Thresholds for Determination of Conflicts/Encounters

The following Table 1 lists the various thresholds used in processing aircraft pairs for conflicts and encounters. Table 1 presents a complete list of the parameters themselves, but the numeric values provided are from previous work. The actual parameters used will be reported in a subsequent report documenting the results of the study.

Table 1: Thresholds for Conflict/Encounter Analysis

Name	Description	Comparator	Threshold
MaxH	Gross filter's maximum horizontal separation distance; positions that are beyond this threshold are discarded for consideration of conflicts or encounters	>	30 nautical miles
MaxV	Gross filter's maximum vertical separation distance, beyond which position reports are not considered as conflict and encounter	>	5000 feet
EncMinSepH	Encounter minimum horizontal separation distance; if less, then an encounter may have occurred	<	30 nautical miles
EncMinSepV1	Encounter minimum vertical separation distance; if less, then an encounter may have occurred for non Reduced Vertical Separation Minima (RVSM) aircraft	<	4000 feet up to and including FL 290 and 5000 feet above
EncMinSepV2	Encounter minimum vertical separation distance; if less, then an encounter may have occurred for RVSM aircraft	<	4000 feet
CflMinSepH	Conflict standard minimum horizontal separation distance; if less, then a conflict may have occurred	<	5 nautical miles
CflMinSepV1	Conflict standard minimum vertical separation distance; if less, then a conflict may have occurred for non RVSM aircraft	<	1000 feet up to and including FL 290 and 2000 feet above
CflMinSepV2	Conflict standard minimum vertical separation distance; if less, then a conflict may have occurred for RVSM aircraft	<	1000 feet
MinTm	Minimum conflict duration threshold, duration is the end time of the conflict (last pair of position reports in conflict) subtracted by the start time of the conflict (first pair of position reports in conflict), if duration is less, then conflict not generated	<=	6 seconds
MergeTm	Maximum merge time between multiple conflicts, time interval is the start time of current conflict subtracted by the end time of the previous conflict; if this time interval is greater, then two conflicts else conflicts are merged into one	>	40 seconds
TrackInt	Time interval of time-synchronized and interpolated position reports, thus all conflicts and encounter separations are reported based on this interval size	=	10 seconds

3.2 Analysis of the Output Data

The output data being analyzed in this study are the tactical, aircraft to aircraft, conflict alerts generated by the HCS. The conflict alert messages are captured by a special IIF developed interface that redirects the conflict alerts being posted to the ARTCC's high speed printer to a Common Message Set (CMS) General Information (GH) message. This data is then recorded by the local IIF HADDS device. As part of this study the Simulation and Analysis group developed software that parses GH messages, organizes them into groups called Notification Sets (defined in the following Section 3.2.2), and stores them to a relational database table for further accuracy analysis. The accuracy measurements consist of determining which of the alert messages are valid, which are in error (false or nuisance alerts) and which conflicts are not predicted in a timely manner (missed). These cases are defined in Section 3.2.1 and the processing to determine their counts are presented in Sections 3.2.3 through 3.2.4. In Section 3.3 metrics are defined that give a statistical summary of the overall conflict prediction accuracy of the system.

3.2.1 Conflict Alert Accuracy Basic Cases

An alert by the conflict probe, in this case the HCS's conflict alert function or ERAM's replacement safety alert function, is captured as Notification Sets (NS). The details of how these NSs are defined will be explained in detail in the next section, Section 3.2.2. The alert processing is the comparison of the set of NSs generated by the HCS against the set of conflicts determined off line from the input scenario. These simultaneous events fall into four cases as illustrated in Table 2.

Table 2: Basic Cases of Conflict/Notification Set Events

	Notification Set (NS) Posted	**Notification Set (NS) Not Posted**
Conflict Occurs	**CASE 1**: there is a conflict and there is a NS posted against it – valid alert (**VA**)	**CASE 2**: there is a conflict and no NS is posted for it – a missed alert (**MA**)
Conflict Does Not Occur	**CASE 3**: there is no conflict but there is a NS posted – a false or nuisance alert (**FA**)	**CASE 4**: There is no conflict and there is no NS - correct no-call (**NC**)

These cases are further subdivided into 16 different cases in the processing. This refinement of the events in the scenario is done to identify details of the conflicts and encounters. In addition, because of the nature of the test scenario, it is necessary to discard both some of the conflicts and some of the NSs when computing the performance statistics of the tactical alert function. Several of the 16 cases identify the discards. The 16 cases are listed in Table 3. They are explained later in detail in Section 3.2.4.

The ERAM specification requires that a tactical alert be posted to the Controller's display at least 75 seconds before the start of the conflict but also no more than 135 seconds before the start of the conflict. The warning times are supplied by the post processing of the simulation data.

3.2.2 Construction of the Notification Sets

An alert from the HCS or ERAM identifies a pair of aircraft and estimates when they will lose separation. The alert is posted (or added) to the Controller's display at a specific time and is left up until it is removed at a later time. The alert includes an estimated time of the start of the conflict. This time is usually updated during the time that the alert is posted to the display.

The alerts are assembled into groups whereby all of the alerts in the same group identify the same aircraft pair. The earliest alert in the group becomes the ADD alert; the latest alert in the group becomes an UPDATE alert. A DELETE alert is added a parameter time after this last alert (e.g. 12 seconds). All of the other alerts in the group become UPDATE alerts. Groups having only one alert are not deleted but have an ADD alert and then a DELETE twelve seconds later. This grouping of alerts is referred to as a Notification Set (NS) and identified internally by a unique alert identification number.

The initial alert message, the ADD, the final alert message, the DELETE, and the UPDATE messages in between form the NS for their aircraft pair. In this analysis only the ADD and DELETE messages are required. However, all these messages are recorded in a relational database table, which are linked by alert identification number and the ACIDs and CIDs (the automation's aircraft identification and computer identification strings) of the aircraft pair involved.

3.2.3 High Level Overview of Processing

This section provides a high level overview of the processing. It gives a quick guide to the processing involved to determine the missed and false alert errors described in Table 2. A much more detailed presentation of the processing including over a half dozen detailed flowcharts and table of events is presented in Section 3.2.4.

The process begins with the simulation run. The simulation is run in real time and the input data and the output data are recorded for post run analysis. The input data needed for analysis are the position reports - latitude, longitude, altitude, and time - of the aircraft in the scenario input to the HCS (or ERAM). These position reports are processed to determine all conflict events, producing a conflict list. The output data needed for analysis are the tactical conflict alert messages produced by the HCS (or ERAM). At minimum a tactical conflict alert message includes two call signs, two computer ID's, and a posting time. These alerts are assembled into a notification set list. Next, these two lists are matched by the aircraft idenfication call signs as illustrated in Figure 2. The process of matching the NSs to the conflicts produces matched NSs or unmatched conflicts, which result in three outcomes: Valid Alerts, Missed Alerts, and Discards. Valid Alerts, as already presented in Section 3.2.1 and Table 2, occur when the conflict has a matching notification set and is presented in a timely manner. This occurs when the notification set was started (first presented) with a warning time greater than or equal to a minimum warning time requirement (MWTR) for the given aircraft-to-aircraft conflict. This results in either a Valid Alert or Missed Alert.

If no matching notification set is found and the conflict is unmatched, a search is performed for any notification set started at or after the actual conflict start time (ACST). If none are present, the event is labeled as a Missed Alert event. If a notification set is found and the both the conflict and the NS starts near the start of track or near a gap in track data, the event is discarded (recorded as a Discard). A conflict that starts near the start of track or near a gap in surveillance track reports of one of the aircraft is referred to as a pop-up.

For the remaining NSs that were not matched, these events are potentially False Alerts (a.k.a. nuisance alerts). As illustrated in Figure 3, four basic checks are performed to verify that the NS is a False Alert or should be discarded. First, the track reports must exist for both aircraft at the NS start and end or the event is labeled a Discard. Second, if an actual conflict exists and the NS's start time is within the duration of this conflict, the NS is discarded. Third, at the NS start time the flights are linearly extrapolated forward in time using past track position reports to predict whether a conflict will occur. If no conflict is predicted, the event is immediately labeled a False Alert. Finally, if a conflict is predicted, more linear expolations are performed within the NS time interval (between it starts and ends). This is iterated until either no conflict is predicted or the end of track occurs for one of the aircraft. If this ending time is near the end of the NS, the NS event is labeled Discard and if not it is labeled as a False Alert. In summary, Figure 2 and Figure 3 provide a quick overview of the processing, while Section 3.2.4 will provide the complete details of the processing involved to evaluate a CPs performance.

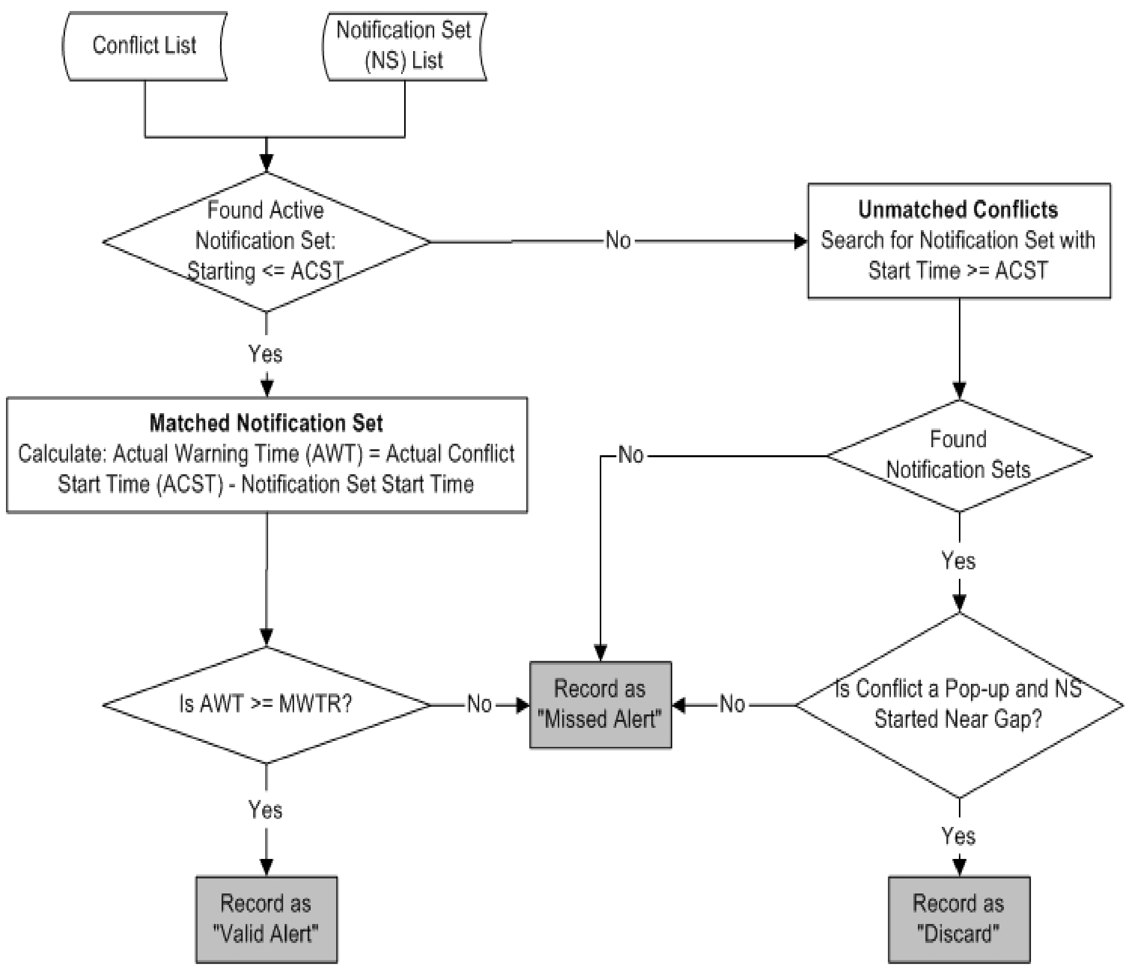

Figure 2: High Level - Processing of Valid and Missed Alert Events

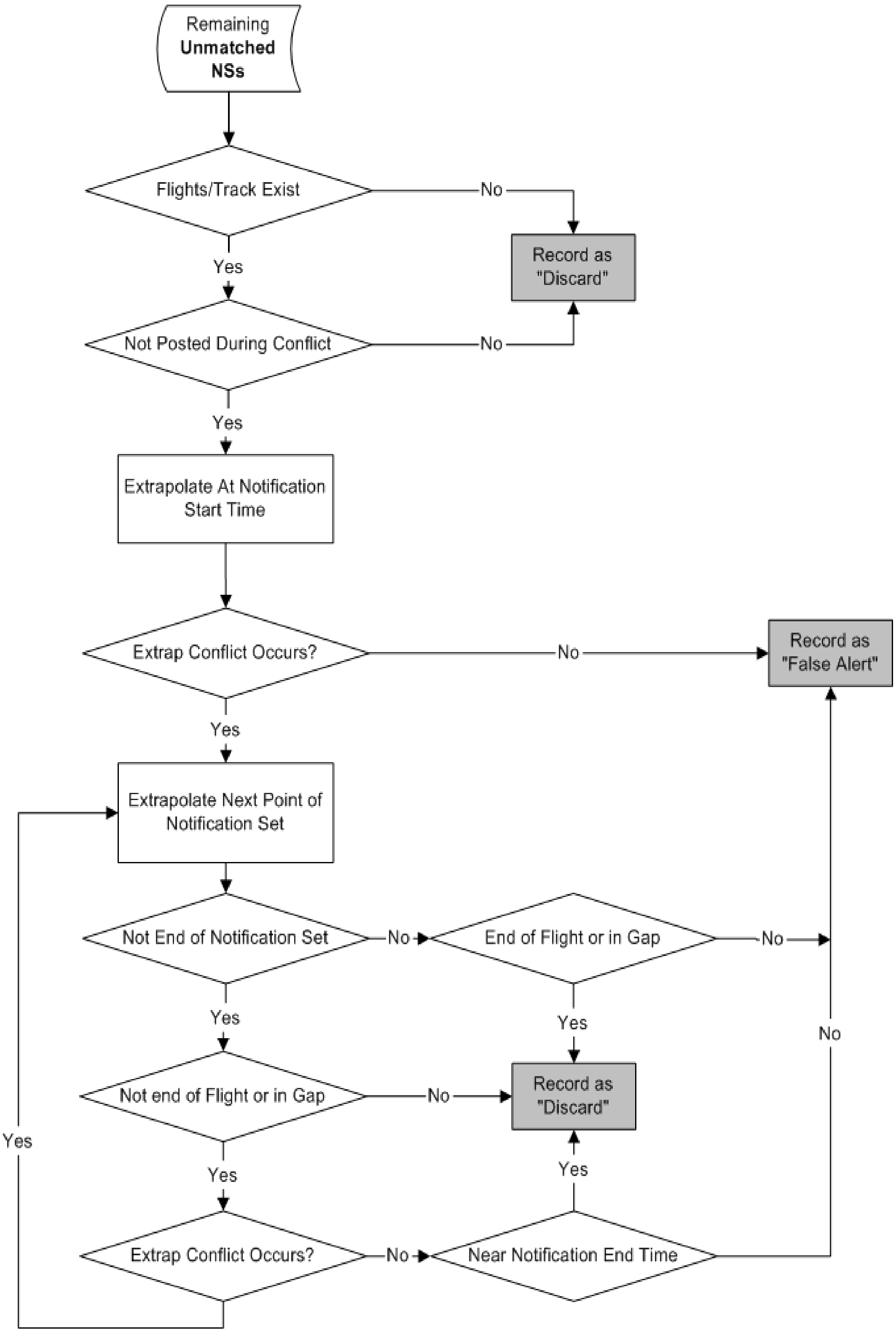

Figure 3: High Level Processing of False Alerts and Discards

3.2.4 Detailed Description of Processing

The actual conflicts in the input scenario are determined by an exhaustive comparison of all of the position reports. The list of notification sets are assembled using the method described in Section 3.2.2. For each aircraft-to-aircraft conflict, a search is made against the list of NS's to see if there is a NS which has the same ACIDs (the same call signs) and the same CIDs (the same computer identification numbers). Three data sets are produced: (1) the set of NS's matched to conflicts, (2) the set of NS's not matched to any conflict, and (3) conflicts not matched to any NS. A NS can be matched to several conflicts, but a conflict can be matched to only one NS. This will be described in detail in Section 3.2.4.1.

Any recording of traffic data (i.e. test scenario) has a determinant beginning and an end. As a result, some of the "errors" in the conflict alerts are not really errors but are artifacts of the finite traffic scenario. Additional processing is required to handle these cases. The processing handles these cases and assigns special codes to them. The four basic cases are subdivided into additional cases, 16 in all. The processing assigns one of the 16 codes to each member of the three sets of matched Notification Sets, unmatched Notification Sets, and unmatched conflicts. The suffixes A and B and 1 and 2 on the codes identify a lower level step in the processing.

Linear extrapolation of the aircraft flight paths is used to both (1) determine whether or not and to discard a false alert and (2) to relax the minimum warning time requirement.

What at the outset looks like a regular conflict alert, may, with additional processing, be further qualified. If the alert was not given at least 75 seconds before the start of the conflict, it is late. If it is late there may have been extenuating circumstances which excuses the lateness. This processing is illustrated in Figure 4.

A conflict which has no matching Notification Set is a Missed Alert, but is further qualified as is shown in the flow chart of Figure 5. The miss may be forgiven if the conflict is a popup and a Notification Set is posted shortly after the conflict start time. A popup conflict is one in which the conflict starts immediately after the start of the aircraft track in the test scenario or near the end of a gap in track data.

An umatched Notification Set is nominally a False Alert. However, its may be discarded or excused. It will be discarded if the flight data is not in the scenario or if there is no track data at the time the alert was posted. It may also be discarded if there is a conflict between the two aircraft and the alert is posted during the conflict or it may be discarded if a maneuver after the posting removed the conflict. A maneuver is detected by the extrapolation test. The processing is illustrated in Figure 6, Figure 7, and Figure 8.

Two specific tests are applied to the data - a radar track extrapolation test to see if a false alert should be counted or discarded and a second radar track extrapolation test to see if the minimum warning time requirement of 75 seconds should be relaxed to a smaller value. These tests are described in detail in the following sub-sections.

3.2.4.1 Matching Notification Sets to Conflicts

The NS's derived from the output alerts of the HCS are matched to the truth conflicts on the basis of their ACIDs and CIDs. Furthermore, to be matched, the NS must be active at the actual conflict start time (ACST). This requires that the NS's start time must fall before the actual conflict start time and NS's deletion must be later than the actual conflict start time. There may exist multiple conflicts for the same aircraft pair, but by definition these conflicts are not time overlapping. However, the same NS could be matched to all of these conflicts if it remains active throughout all their ACSTs. Similiarly, multiple NSs can be generated but cannot be overlapping in time. This ensures each conflict can only have at most one candidate NS to be matched to it. Any unmatched NSs become candidate False Alerts and are sent for further processing (they have the potential to be excused or discarded). Multiple conflicts can be matched to one NS. However, multiple NSs cannot be matched to the same conflict, since NSs cannot have time overlap for the same aircraft pair.

The matching of the NSs with the conflicts in the scenario is illustrated in Figure 4. The matching process results in either (1) a set of matched NS's, (2) a set of unmatched NS's, or (3) a set of unmatched conflicts. Subsequent processing assigns a code to each of the elements in each of the three sets. Each code describes a type of Valid Alert, Missed Alert, False Alarm, or Discarded Alert. The codes have been listed in Table 3. These will be explained in more detail in the following sections.

3.2.4.2 Processing Matched Notification Sets

The comparison of the HCS tactical conflict alerts to the Notification Sets produces a set of Notification Sets which have been matched to actual conflicts in the scenario. If the Actual Warning Time (AWT), the time interval between the start of the NS and the ACST, is greater then 75 seconds the "event" is labeled VA_STD for a Valid Alert, Standard. If it is less than 75 seconds it is checked against the minimum warning time requirement (MWTR) for the conflict, which may be less than 75 seconds. The MWTR of 75 seconds may have been relaxed if there was a last minute maneuver that created the conflict (See Section 3.2.4.3 and Figure 9 for details). If the AWT is greater then the MWTR, the event is labeled VA_LATE. The alert was late, but the lateness was forgiven because of the occurrence of an unpredictable maneuver. If not, the event is labeled MA_LATE. The conflict was detected but not in a timely manner. The flowchart in Figure 4 illustrates these processing steps.

Table 3: Cross Referenced Alert Designator Codes

NO.	ALERT DESIGNATOR	ALERT TYPE	DESCRIPTION	DATA SET	FIG NO.	SECTION NUMBER
1	VA_STD	VA	VALID STANDARD	Matcthed NS	Figure 4	3.2.4.2
2	MA_STD_A	MA	MISSED STANDARD A	*Unmatched Conflict*	Figure 5	3.2.4.4
3	MA_STD_B	MA	MISSED STANDARD B	*Unmatched Conflict*	Figure 5	3.2.4.4
4	VA_LATE	VA	VALID LATE	Matcthed NS	Figure 4	3.2.4.2
5	MA_LATE	MA	MISSED LATE	Matcthed NS	Figure 4	3.2.4.2
6	MA_DISCARD	DISCARD	MISSES DISCARD	*Unmatched Conflict*	Figure 5	3.2.4.4
7	FA_STD1	FA	FALSE ALERT STANDARD 1	Unmatched NS	Figure 7	3.2.4.6
8	FA_STD2_A	FA	FALSE ALERT STANDARD 2A	Unmatched NS	Figure 7	3.2.4.6
9	FA_STD2_B	FA	FALSE ALERT STANDARD 2B	Unmatched NS	Figure 8	3.2.4.6
10	FA_STD3	FA	FALSE ALERT STANDARD 3	Unmatched NS	Figure 8	3.2.4.6
11	FA_ACST_DISCARD	DISCARD	FALSE ALERT NO TRACK DISCARD	Unmatched NS	Figure 6	3.2.4.5
12	FA_EVENT_DISCARD_A	DISCARD	FALSE ALERT EVENT DISCARD A	Unmatched NS	Figure 7	3.2.4.6
13	FA_EVENT_DISCARD_B	DISCARD	FALSE ALERT EVENT DISCARD B	Unmatched NS	Figure 8	3.2.4.6
14	FA_NOTRK_DISCARD1	DISCARD	FALSE ALERT NO TRACK DISCARD 1	Unmatched NS	Figure 6	3.2.4.5
15	FA_NOTRK_DISCARD2	DISCARD	FALSE ALERT NO TRACK DISCARD 2	Unmatched NS	Figure 6	3.2.4.5
16	FA_NOTRK_DISCARD3	DISCARD	FALSE ALERT NO TRACK DISCARD 3	Unmatched NS	Figure 8	3.2.4.6

3.2.4.3 Relaxation of the Minimum Warning Time Requirement

An alert is *valid* when it correctly identifies an impending conflict in a timely manner. The alert is timely if and only if the NS is posted between the required 135 seconds and 75 seconds before the first loss of separation, referred to as the actual conflict start time (ACST). The alert must be posted when the conflict starts. The nominal minimum warning time requirement (MWTR) is 75 seconds. This value may be reduced or relaxed under special circumstances. An extrapolation method is used to determine whether or not the warning time requirement should be relaxed.

All maneuvers except a leveling off at a cleared altitude are unpredictable by the tactical alert processing. If an unpredictable maneuver, less than 75 seconds before the start of the conflict, puts the aircraft pair into conflict, the minimum warning time requirement (MWTR) is reduced (relaxed) to the time interval between the maneuver and the start of the conflict. This is the motivation of relaxing the MWTR. The maneuver is only detected implicitly by linearly extrapolating to detect conflicts. If a conflict cannot be predicted by linear extrapolation of the flight paths of the two aircraft 75 seconds before the start of the conflict, the warning time requirement must be reduced to some value less than 75 seconds.

The reduced MWTR is found by selecting the last track point before the start of the conflict and predicting, using linear extrapolation, where the two aircraft will fly. If the track extrapolations predict a loss of minimum required separation, that is, a conflict, the immediately preceding track points are selected and the extrapolation is repeated. If a conflict is still predicted, another step backwards is taken and the extrapolation is repeated. This backward search continues until a conflict is not predicted or the search has reached 75 seconds before the ACST. The new MWTR is the difference in times between the latest track point predicting a conflict and the ACST. If the predicted conflict does not drop out of the backwards search before the 75 seconds search limit is reached, the MWTR remains at 75 seconds. This determination of a, possibly new, MWTR is illustrated in the flow chart in Figure 9.

3.2.4.4 Processing Unmatched Conflicts

The comparison of the HCS tactical conflict alerts to the NSs also produces a set of conflicts which have not been matched to NSs. These conflicts are nominally Missed Alerts; however, they may be discarded if the conflict is a confirmed pop-up event and if the NS begins near the beginning of a track start or restart (i.e. a restart occurs only after a gap in track reports). A pop-up conflict occurs when the conflict starts at or very close to the beginning of one or both of the aircraft tracks. If the conflict is not a pop-up it is labeled as a Missed Alert, MA_STD_A. If it is a pop-up, a further check is made to see if there is a NS which matches the two aircraft in conflict, is posted after the ACST and begins within a parameter time of the beginning or restart of track of at minimum of one of the aircraft pair. If the NS satisfies these conditions, the conflict is discarded as a MA_DISCARD. If the conflict is a pop-up but does not have such a NS, it is labeled a Missed Alert, MA_STD_B. This processing is illustrated in Figure 5.

3.2.4.5 Processing Unmatched Notification Sets

The comparison of the generated conflict events to the NSs produces a third data set for further processing. This data is the set of NSs which have not been matched to conflicts. The unmatched NS's are nominally False Alert events but may be excused or discarded under special circumstances. An alert without a conflict may be excused if an unpredictable maneuver removed the conflict, if there is no track data available to evaluate the alert, or if there was a conflict but the alert was posted during a conflict. Being an unmatched NS, this NS could not have been matched because it was posted after the ACST. There may or may not be another NS which was matched to the same conflict.

The input data for the third flowchart, Figure 6, as indicated by the connector B, is the set of unmatched NSs. These NSs are potentially False Alert events. A check is made first to see if there is track data for both aircraft in the scenario. If the track data is missing, it is impossible to determine whether or not there was a conflict and consequently the NS is discarded and labeled FA_NOTRK_DISCARD1. If there is track data, a check is made to see if there is track data at the posting or start time of the NS. If there is no track data at this time it is not possible to later apply the extrapolation test and therefore the NS is discarded and labeled FA_NOTRK_DISCARD2.

To remove the complication of procedural separations near Terminal Areas present in the data set, the analysis was restricted to Flight Level 180 and above. In normal live traffic, the track data would be present throughout the aircraft's flight, but due the mechanics of recording these messages and removal of data below Flight Level 180, a significant part of the track data had to be removed and therefore these rules protect this from skewing the performance results.

Next, the process determines if there was a conflict between the two aircraft listed in the NS. If there was a conflict which was not matched to the NS, it was either because the alert was not posted before the conflict started (before the ACST), or because it was deleted or retracted before the conflict started (before the ACST). In the former case the NS is discarded (FA_ACST_DISCARD); in the latter case the NS is a possible false alert and is sent for further processing (discussed in Section 3.2.4.6 and Figure 7). If there is no conflict between the aircraft pair, the unmatched NS is also a possible False Alert and is sent for the same further processing.

3.2.4.6 Extrapolation for False Alert Forgiveness

If the NS has not been discarded at this point, linear extrapolation test is applied to evaluate the event. This test determines whether or not an unpredicted and unpredictable maneuver by either of the aircraft has removed a potential conflict. There may or may not be a conflict between the two aircraft in the alert; it there is a conflict it has not been matched to the Notification Set. Recall that the matching requires that the Notification Set be active at the start of the conflict.

The HCS has, at the time of posting the alert, predicted a conflict. The extrapolation test checks this prediction to see if it agrees with the prediction. This test makes its own prediction, assuming that both aircraft will continue their flight paths, flying straight, maintaining the same course, the same ground speed, and the same rate of climb or descent.

The fourth flowchart in Figure 7 describes the initial processing when there is an unmatched NS. There may or may not be a conflict. If there was going to be a conflict but an unpredictable maneuver eliminated the conflict, the NS can be discarded. The maneuver is detected by extrapolating the flight paths of the two aircraft and seeing if they conflict. If the extrapolation produced a conflict, but no conflict actually occurred, there must have been a maneuver to take the aircraft out of conflict.

Usually the posting time of the alert will fall between two track sample times. Extra logic is required to handle this situation, shown in the flow chart of Figure 7. The logic after processing these two points, which bracket in time the posting of the alert, is given in the flowchart of Figure 8.

For the NS to be discarded there must (1) be continuous extrapolated conflicts beginning at the start of the NS, and (2) these extrapolated conflicts need to end near (in time) the end of the NS. Nearness is defined by a parameter time interval. If there is no extrapolated conflict at the start of the NS, the False Alert is labeled FA_STD1. If there is an extrapolated conflict for the entire duration of the NS, it is concluded that there was no maneuver to excuse deletion of the alert and labeled FA_STD3. If there is an extrapolated conflict at the start of the NS, extending through the NS and then ending at approximately the same time that the alert is dropped, the False Alert is excused and labeled FA EVENT DISCARD (Type A or B). If the extrapolated conflict ends, but not when the alert is dropped (i.e. the NS ends), it is counted as a False Alert and labeled FA_STD2 (Type A or B).

The flowchart in Figure 7 describes the extrapolation processing for the first two track points in the two aircraft tracks at the start of the NS. If a FA_STD2 is found in Figure 7, it is labeled as FA_STD2_A. Similarly if a FA_EVENT_DISCARD is found in Figure 7, it is labeled FA_EVENT_DISCARD_A. The flowchart in Figure 8 describes the extrapolation process for the remainder of the NS. The FA_STD2 and FA_EVENT_DISCARD are labeled there as FA_STD2_B and FA_EVENT_DISCARD_B.

There may not be track data available for the duration of the NS. In this case it is not possible to determine whether or not the extrapolation continuously predicts a conflict. Under these conditions, the NS is discarded and labeled FA_NOTRK_DISCARD3. All these labeled events are summarized in Table 3.

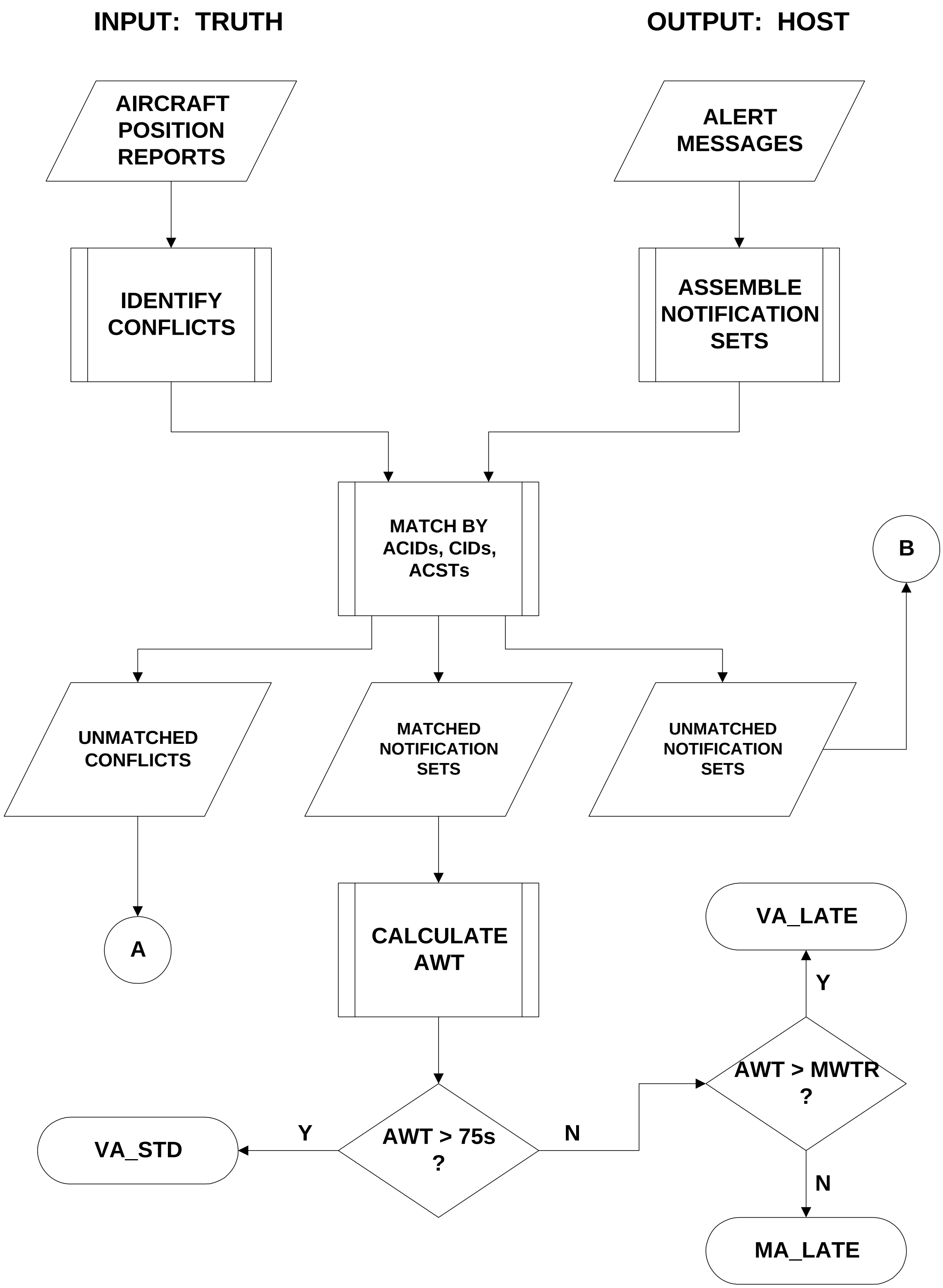

Figure 4: Matching the Notification Sets for Missed and Valid Alerts

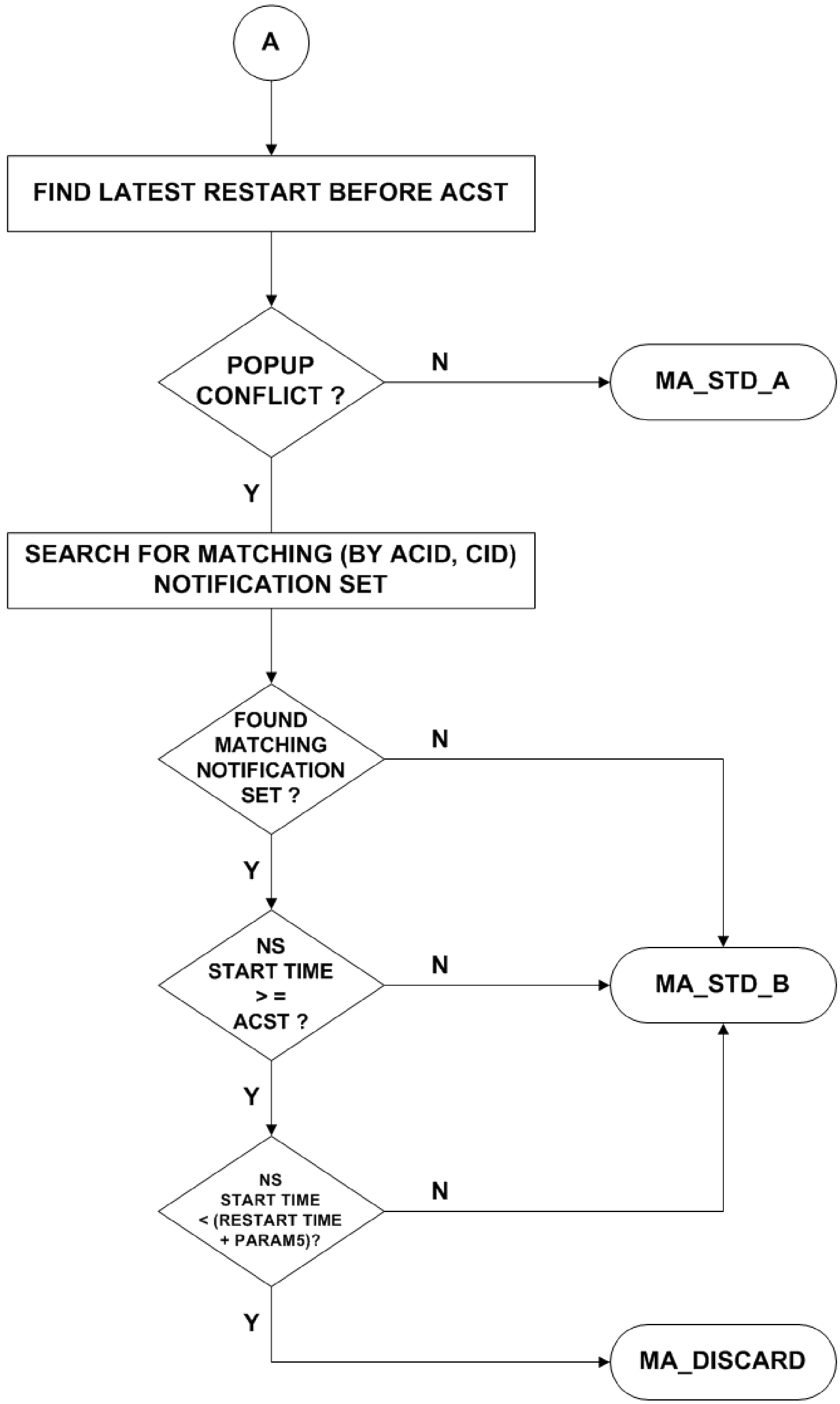

Figure 5: Checking Unmatched Conflicts

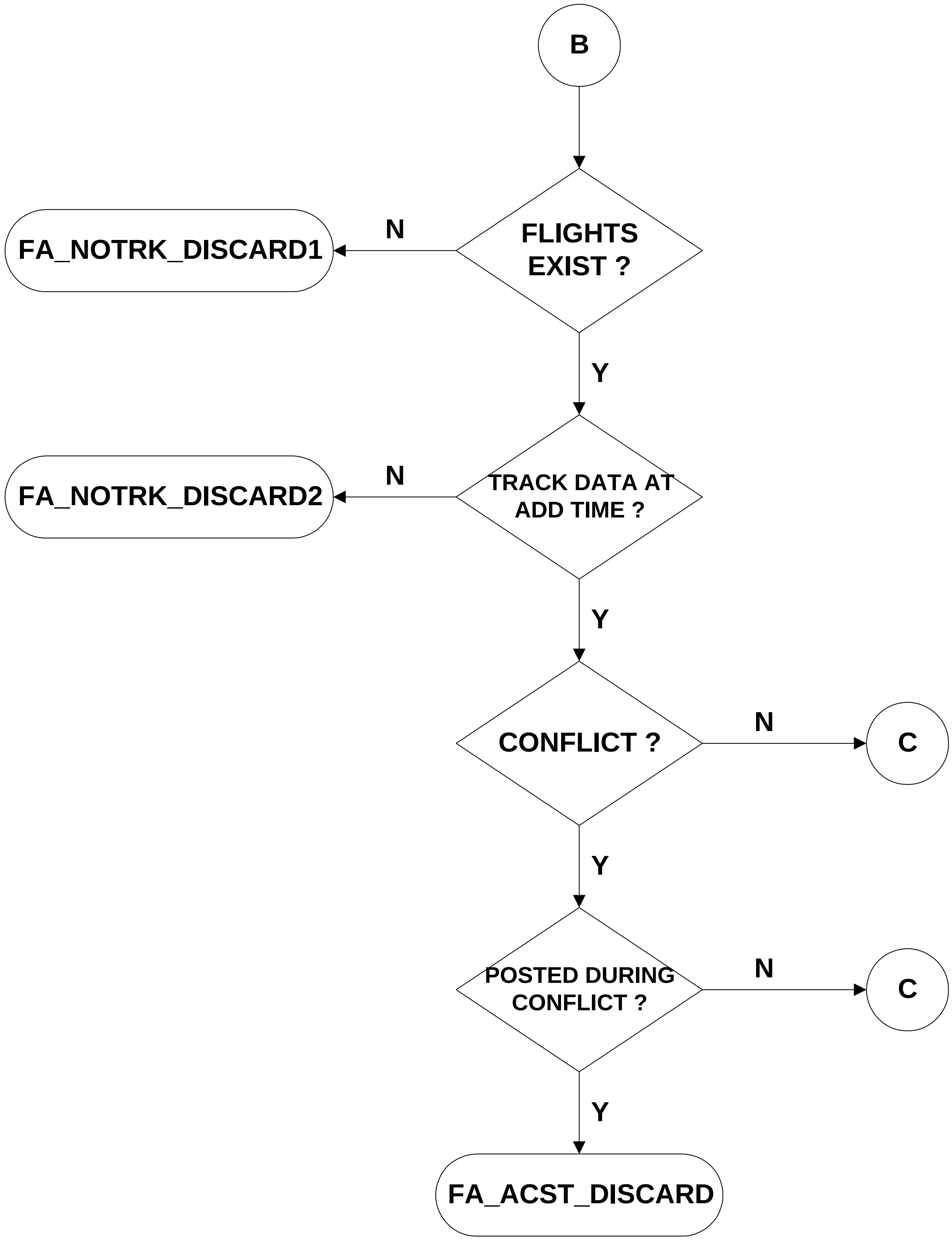

Figure 6: False Alert Checking

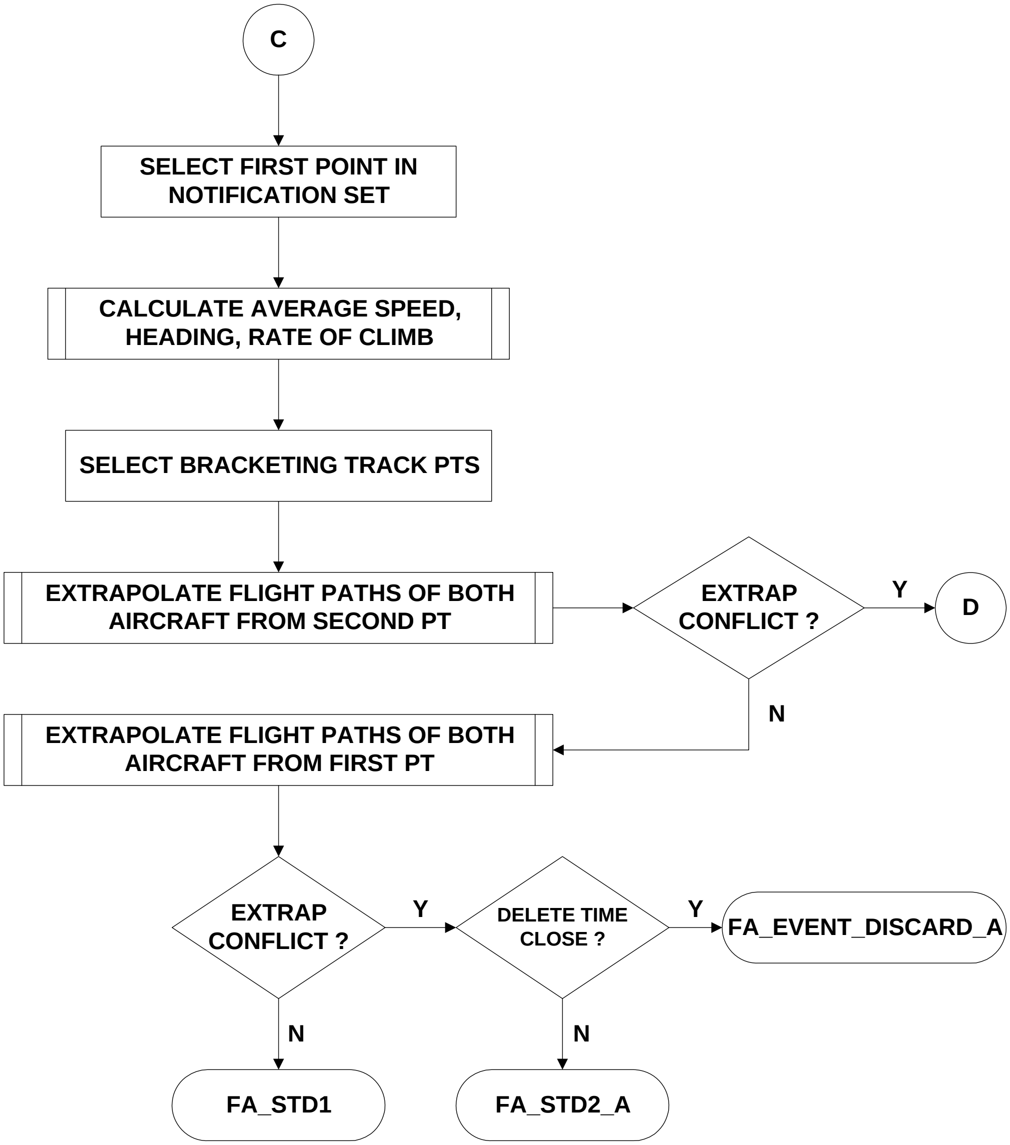

Figure 7: Extrapolation for False Alert Forgiveness 1

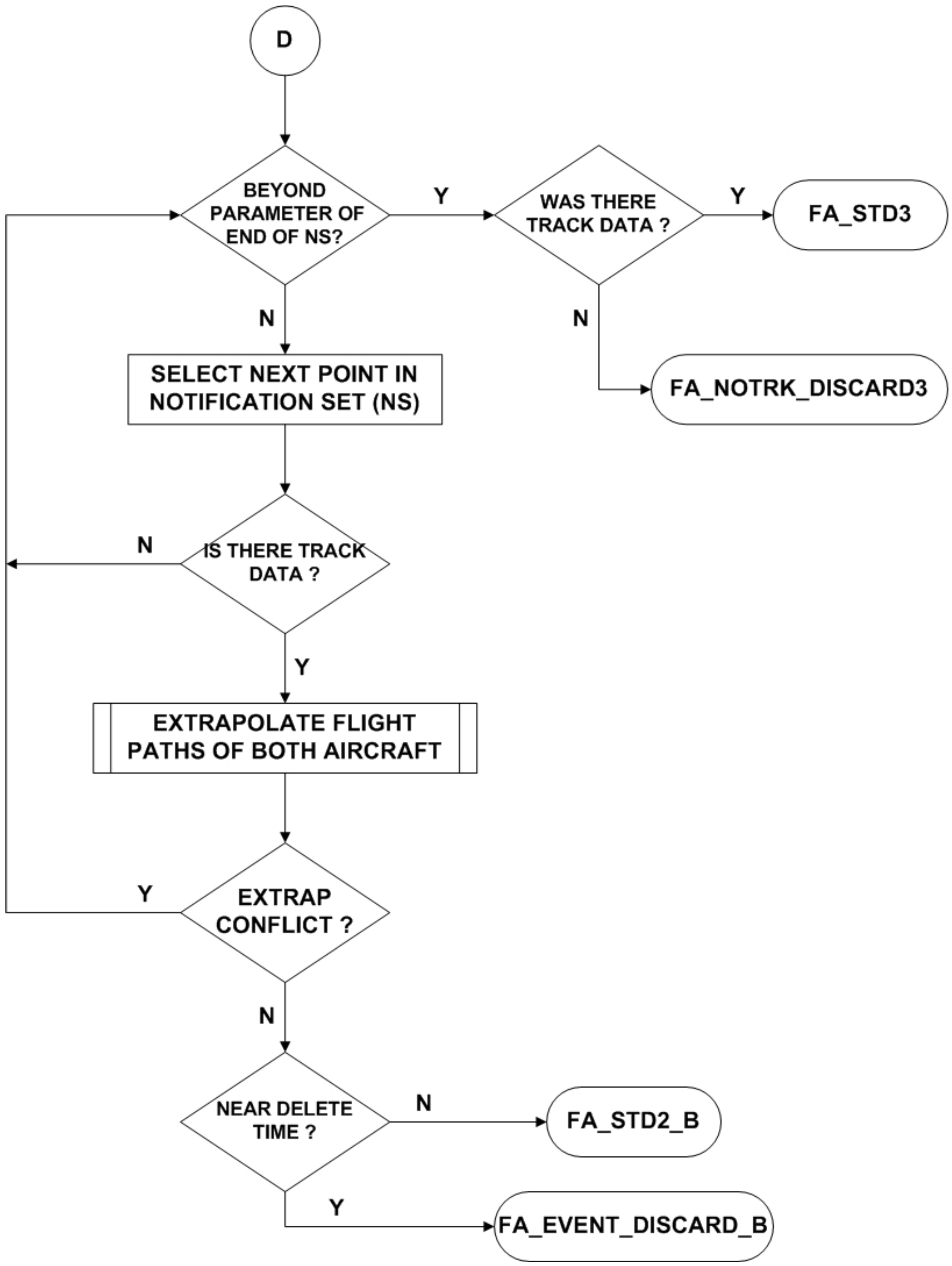

Figure 8: Extrapolation for False Alert Forgiveness 2[1]

[1] The parameter time value within the first decision block within Figure 8 is defined in Table 5 as *timeP1*.

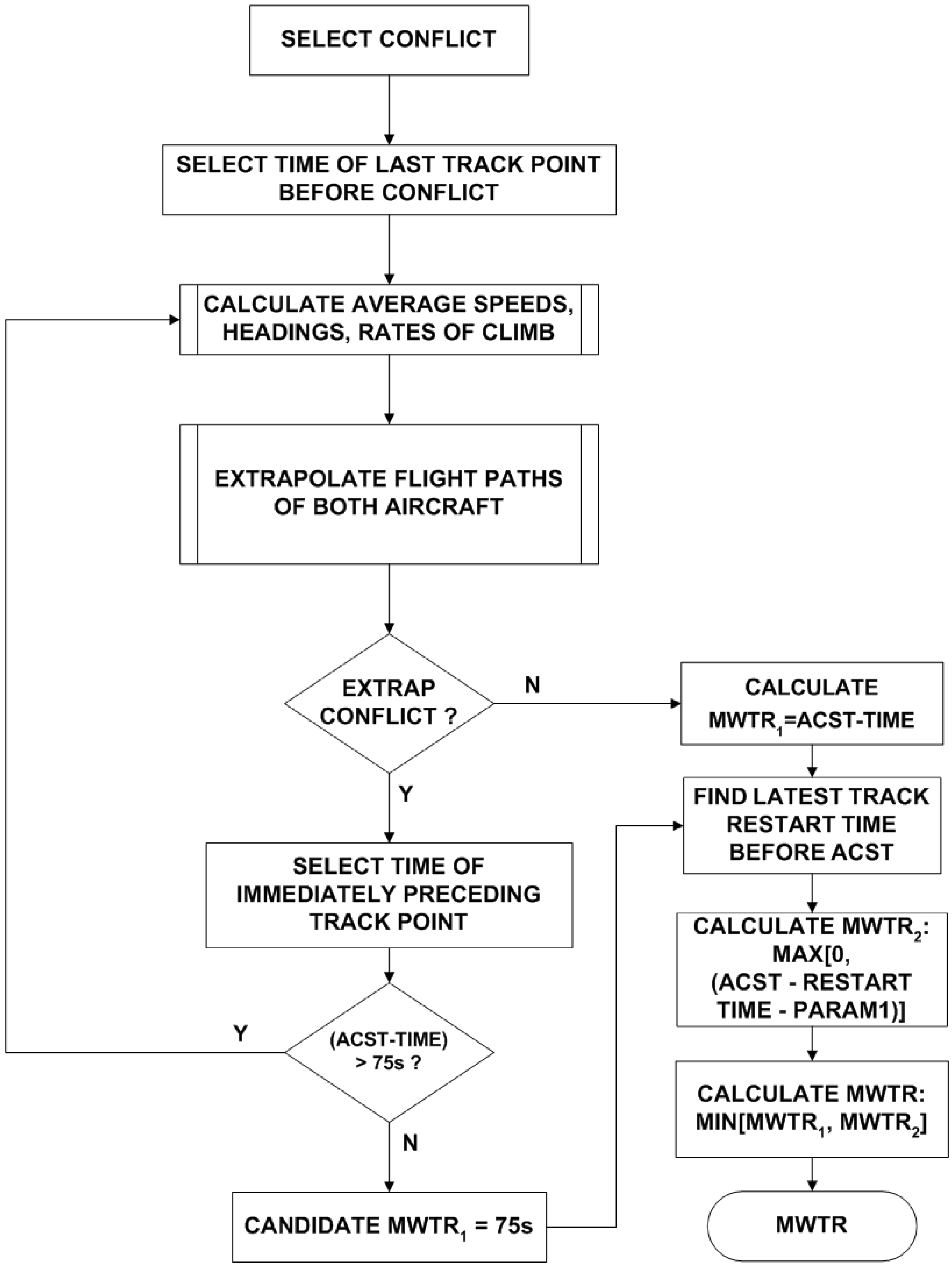

Figure 9: Extrapolation for Relaxation of the Minimum Warning Time Requirement

3.3 Performance Metrics

A complete evaluation of a conflict probe has two complementary aspects: qualitative and quantitative. A qualitative evaluation generally involves real-time testing of conflict probe features and user interface through human-in-the-loop simulations and field tests; for example, (Brudnicki and McFarland, 1997), (McNally et al, 1998) and (Van Doorn et al, 2001) describe real-time testing of various conflict probe capabilities. A quantitative evaluation generally involves non-real-time testing directed at the conflict detection “engine” that underlies the features and user interface of a conflict probe. A comprehensive methodology for quantitative evaluation of a conflict probe is presented in (Bilimoria, 2001); an application of this evaluation methodology has been reported in (Loureiro et al, 2001). Generic metrics for quantitative evaluation are available in (Paglione et al, 1999). Conflict probe performance metrics are presented in (Brudnicki and McFarland, 1997), using a hybrid approach involving data collection and transformation models applied to a recorded air traffic scenario.

There are many metrics that can be applied in evaluating the performance of conflict predictions as referenced above. The metrics presented in this paper are adapted mainly from (Paglione et al, 1999), (Cale, et.al. 1998), and later in (Paglione et al, 2004). The categories include (1) the measurements of estimating the error events of the Missed and False Alerts, (2) the measurements quantifying the timeliness of the correct predictions, Valid Alerts, (3) the metrics related to the prediction stability of these predictions, and finally (4) prediction sensitivity measurements that quantify the overall performance of the accuracy predictions such as sharpness as defined in (Paglione, et.al., 1999). This paper will present definitions of the Missed and False Alert rates and timeliness metrics. This will be presented in the following Section 3.3.1 and Section 3.3.2, respectively.

3.3.1 Error Event Rates

The Missed and False Alert counts are normalized by dividing them by the number of conflicts, non-conflict encounter events, or notification sets they are matched to. The resulting ratios estimate the expected rates of Missed and False Alert events.

3.3.1.1 Missed Alert Rate

Equation 2 defines the rate of Missed Alert events. It quantifies the frequency the conflict probe does not predict the conflict when it occurs.

$$R_{MA} = \frac{MA}{C}$$ **Equation 2**

where *MA* is the number of missed alerts and *C* is the number of valid input conflicts from the scenario and defined further by the following Equation 3. It is the sum of Missed Alerts and Valid Alert events[2]. Note: Equation 3 purposely does not include the number of discarded conflicts as discussed in Section 3.2.4.4.

$$C = (MA + VA)$$ **Equation 3**

[2] Equation 3 can be expanded by referring to the equilvalent alert designators from Table 3, such that $MA = (MA\_LATE + MA\_STD\_A + MA\_STD\_B)$ and $VA = (VA\_STD + VA\_LATE)$.

3.3.1.2 False Alert Rate

The main definition of the False Alert Rate is the expected frequency in predicting a conflict when two aircraft are close together but not close enough to violate the minimum required separation. Now the False Alert Rate measures how likely it is that a conflict will be predicted when the two aircraft get close enough together so that there is a possibility of a conflict. In other words, it is the rate of the non-conflict event (encounter) being a predicted as a conflict (an alert or NS). This rate is a ratio where the numerator is clear. It will always contain the number False Alert events. However, the demoninator has several possibilities. For counts of the encounters, how close is close? To provide a full view of performance, close enough should include a set separation distances, varying from a legal conflict standard to several times this legal limit. In particular, a threshold distance is used called the min-max ratio that combines both the vertical and horizontal dimensions into one measure, which is defined in Section 3.3.1.2.1. Next, the False Alert Rates defined by these intervals of min-max ratios are presented in Section 3.3.1.2.2.

Another definition of False Alert Rate is the expected frequency your predicted conflict, as defined as a NS, is not a true conflict. In other words, the rate the given NS is false. The numerator is again the number of False Alert events. The denominator is the quanity of total alerts or NSs (all except the discarded events). This metric is presented in Section 3.3.1.2.3.

3.3.1.2.1 Definition of the Min-Max-Ratio

The separation distance of two aircraft is measured using a variable which combines the horizontal separation and the vertical separation. This concept was first published by the FAA in (Paglione et al, 1997) and later in (Paglione, et.al., 1999). The horizontal separation in nautical miles is normalized by dividing the value by 5 nautical miles, which is the minimum horizontal separation allowed in en route airspace when there is insufficient vertical separation. The vertical separation in feet is normalized by dividing the value by 1000 feet[3], which is the minimum vertical separation allowed when there is insufficient horizontal separation. An aircraft pair can be separated either horizontally or vertically (or both). The critical separation is the maximum of the horizontal and vertical separation. The min-max ratio is defined to be the maximum of the two normalized separations defined above. The symbol ρ is used in this report to represent the min-max ratio. The aircraft pair is in conflict whenever the min-max ratio falls below one, and conversely they are not in conflict when the min-max ratio is greater than one.

The following Equation 4 expresses the quantity of min-max ratio, ρ.

$$\rho = \min_0^n\left(\max\left(\left(\frac{horz\_separation}{std\_horz\_separation} \right), \left(\frac{vert\_separation}{std\_vert\_separation} \right) \right)_i \right) \qquad \textbf{Equation 4}$$

where for the given aircraft pair the *std_horz_separation* and *std_vert_separation* contain the standard horizontal separation (e.g. 5 nautical miles) and vertical version (e.g. 1000 feet), respectively. The *horz_separation* and *vert_separation* are the actual horizontal and vertical separations, respectively. Therefore, the ratio for each of these dimensions is combined for every position report *i* and maximum calculated. The minimum of all these maximum ratios from *0* to *n* number of position reports is the min-max ratio, ρ, from Equation 4.

[3] Technically, this is only for Reduced Vertical Separation Minimum (RVSM) certified aircraft. If either aircraft are not RVSM certified and above Flight Level 290, they are required to have 2000 feet separation.

3.3.1.2.2 Min-Max Ratio Interval Count Denominator

The min-max ratio is then calculated from the subset time overlapping aircraft pairs from the full $\frac{n(n-1)}{2}$ aircraft pairs (with *n* being the number of aircraft) from the supplied air traffic scenario. The False Alert Rate is calculated by taking a count of all the pairs of aircraft that have a min-max ratio within an interval of specified minimum separation distances. For example, an interval can be between 1.0 and 1.5 ρ. The numerator is the count of FA events with associated aircraft pairs within the same interval, $1.0 \le \rho < 1.5$. The denominator includes the count of aircraft encounters with a min-max ratio between the same intervals. This is expressed in the following Equation 5, which expresses this rate.

$$R_{FA(1.0 \le \rho < 1.5)} = \frac{FA_{1.0 \le \rho < 1.5}}{E_{1.0 \le \rho < 1.5}}$$ **Equation 5**

where $FA_{1.0 \le \rho < 1.5}$ is the total number of False Alert events with associated alerts with a ρ from Equation 4 within the interval greater than and equal to 1.0 to less than 1.5, and $E_{1.0 \le \rho < 1.5}$ is the number of encounters within the same interval.

Therefore, the FA Rate in Equation 5 was defined with one interval of threshold values for the min-max ratio, ρ. A set of intervals of ρ should be defined: for example define $\rho_0 = 0$, $\rho_1 = 1$, $\rho_2 = 2$, $\rho_3 = 3$, up to $\rho_5 = 5$. Thus, the encounters are grouped according to their min-max ratio values. Some with min-max values between ρ_0 and ρ_1, go into bin 1 (conflicts), those with min-max ratio values between ρ_1 and ρ_2 go into bin 2, and so forth.

Define E_i to be the number of encounters in bin (i), i = 0, 1, 2, 3, to n where the i refers to the i^{th} bin and n the maximum bin index to analyze. Thus, each bin is as follows: bin 0 is $0 \le \rho < 1.0$, bin 1: $1.0 \le \rho < 2.0$, bin 2: $2.0 \le \rho < 3.0$, so forth. Define FA_i to be equal to the number of encounters in bin (i). The False Alert Rate, R_{FAi}, is defined for the i^{th} bin by the following Equation 6.

$$R_{FA(i)} = \frac{FA_i}{E_i}$$ **Equation 6**

Again, *i* is the index of the bin, FA_i is the number of false alerts matched to encounters in a given bin *i* defined by the min-max-ratio and *Ei* is the total number of encounters for the same bin present in the input test scenario.

There are a couple of practical issues to consider in implementation of these metrics in Equation 5 and Equation 6. Some False Alert events are associated with encounters that are beyond the defined threshold of ρ and thus may never get counted in any bin. A solution is to include them in the largest binned rate. For example, the interval of $y \le \rho < z$ is defined for bin *z*. To include the additional False Alerts larger than *z*, it is necessary to alter the interval to $\rho \ge y$, where *y* is the lower bound of the interval. The numerator includes all the FA events above the lower bound of the interval and the denominator includes the encounter pairs with a min-max ratio within the interval, $y \le \rho < z$ plus the count of FA events with a min-max ratio above the upper bound. This largest bin *z* can be expressed by the following Equation 7.

$$R_{FA(\rho \geq y)} = \frac{FA_{\rho \geq y}}{\left(E_Z + FA_{\rho \geq z}\right)}$$ **Equation 7**

where $FA_{\rho \geq y}$ is the total number of False Alert events with a ρ equal to and greater than *y*, E_Z is the number of encounters with a ρ from Equation 4 within the interval equal to and greater than *y* and less than *z*, and $FA_{\rho \geq z}$ is the number of False Alert events that are associated with encounters that have a ρ from Equation 4 equal to and greater than *z*.

The lowest interval includes FA events that are associated with ρ values less than one, potentially conflict events. This can occur when an alert is presented and removed before the true conflict begins. If another alert is not presented in a timely fashion, the probe will earn both a Missed and False Alert. The metric for this lowest bin is presented in the Equation 8 below.

$$R_{FA(0 \leq \rho < 1.0)} = \frac{FA_{0 \leq \rho < 1.0}}{\left(E_{0 \leq \rho < 1.0}\right)}$$ **Equation 8**

where $FA_{0 \leq \rho < 1.0}$ is the total number of False Alert events with a ρ less than 1.0, $E_{0 \leq \rho < 1.0}$ is the number of encounters with a ρ from Equation 4 within the interval from greater than and equal to zero to less than 1.0. This is the zero bin, ρ_0, where the encounters may or may not be conflicts. All conflicts must fall within this lowest bin to be a conflict, but also some encounters in this bin are not conflicts. This is due to a minimum time duration requirement for determining conflicts (e.g. greater than 6 seconds or one track report, see minTm parameter in Table 1).

3.3.1.2.3 Non-Discarded Notification Set Count Denominator

As discussed above, the False Alert Rate can be defined as the rate the given *NS* is falsely predicted. The following Equation 9 expresses this metric.

$$R_{FA} = \frac{FA}{A}$$ **Equation 9**

where *FA* is the number of False Alerts and *A* is the number of valid input NSs produced by the conflict probe input with the given traffic scenario. It is defined further by the following Equation 10.

$$A = \left(FA + VA + MA\_LATE\right)$$ **Equation 10**

where again *FA* is the number of False Alerts, *VA* is the number of Valid Alerts, and *MA_LATE* is the number of late Missed Alert events as defined in Section 3.2.4.2[4].

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[4] The number of False Alert and Valid Alert events in Equation 10 can be expanded from Table 3's alert designators where $\text{FA} = (FA\_STD1 + FA\_STD2\_A + FA\_STD2\_B + FA\_STD3)$ and $\text{VA} = (VA\_STD + VA\_LATE)$.

3.3.2 Timeliness Metrics

Timeliness metrics for conflict predictions serves to estimate the amount of prediction time provided for valid predictions. This is referred to as the warning time. Completely consistent with Actual Warning Time (AWT) used to determine the Valid Alerts as defined in Sections 3.2.3 and 3.2.4.2 and illustrated in Figure 2 and Figure 4, the AWT is calculated from taking the difference from the actual conflict start time (ACST) by the start time of the NS. This is performed only for the set of matched NSs evaluated as Valid Alerts. This is expressed in Equation 11 below.

$$AWT = ACST - NS_{t_0}$$ **Equation 11**

where *AWT* is the Actual Warning Time and *ACST* is the Actual Conflict Start Time, and NS_{t_0} is the start time of the NS evaluated as a Valid Alert.

Standard descriptive statistics on the *AWT*, such as average, median, standard deviation, and percentiles, are calculated for the population of Valid Alerts. Histograms and other data visualization methods can all be employed to analyze these time intervals as well.

3.4 Sample Events

Two sample events are presented to illustrate the conflict prediction alert processing just described and show the type of errors that are being measured in the overall statistics.

3.4.1 Missed Alert Example

This section will present sample flight examples exhibiting a missed alert event either by being late in the posting of the alert or not presenting an alert at all before the ACST.

3.4.1.1 Flight Description

In this example, Flight TEST1 is a Boeing MD80 series aircraft flying from Palm Beach, FL to LaGuardia airport in New York City, with intermediate fixes at PERMT, ILM, TYI, HPW, PXT, and KORRY3. Flight TEST2 is an Airbus A300 series aircraft flying from Orlando, FL to Boston, MA, with intermediate fixes at CHS, JFK, and ORW3. During the time frame of this example, both aircraft were assigned to and were flying at FL350. Figure 10 below depicts the flight paths of these two aircraft immediately before and after the Conflict that occurred.

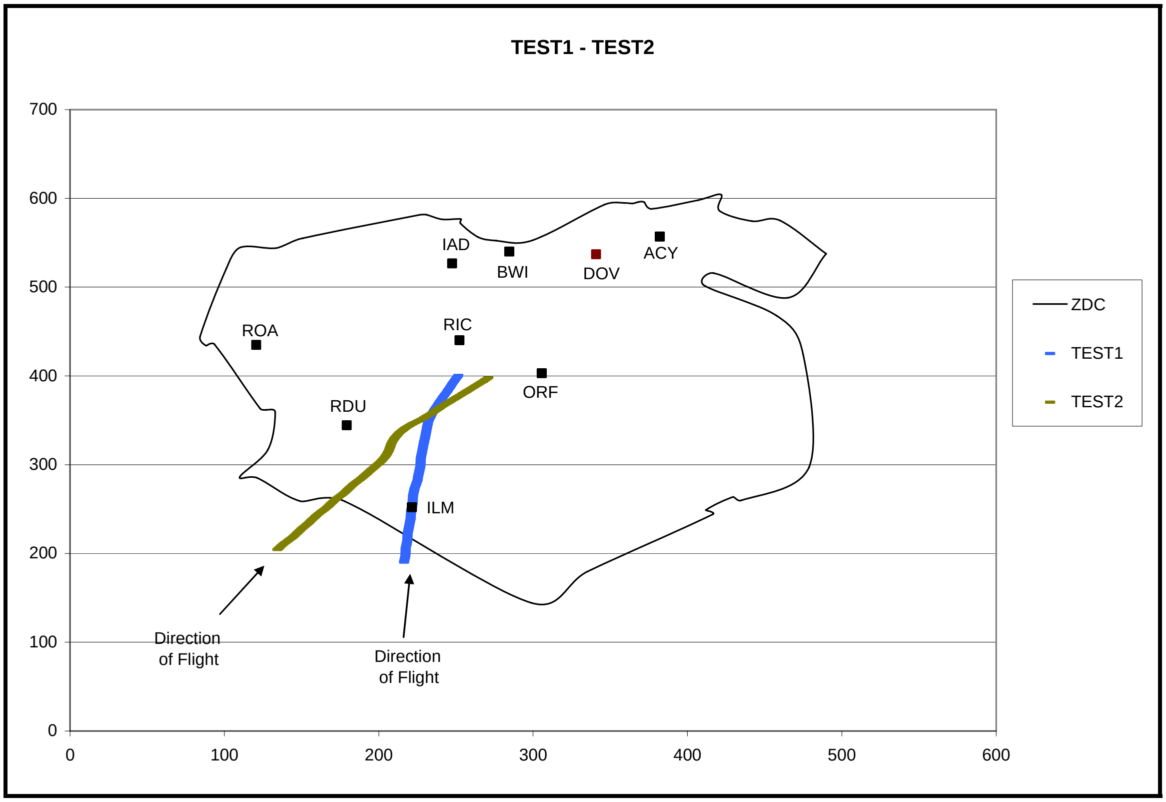

Figure 10: Flight Paths of Flights TEST1 and TEST2

3.4.1.2 Conflict Geometry

Track data for these two aircraft within Washington Center airspace started at 82130 seconds into the scenario. At this point TEST1 and TEST2 were each flying at FL350, were separated by 22.5 nm, and were flying headings of 19 and 3 degrees respectively, resulting in an encounter angle of 16 degrees. Over the next five minutes, both aircraft gradually turned right, the TEST2 aircraft more so, such that at the time of Conflict start, 82430 seconds into the scenario, the encounter angle had increased to 36 degrees. During the conflict, the TEST1 flight continued a gradual turn to the right, towards the TEST2 aircraft, until at the time of Conflict end at 82560 seconds into the scenario the encounter angle had decreased to 23 degrees. During the Conflict, the point of closest approach for the two aircraft was 2.09 nm at 82480 seconds into the scenario.

Scenario track data related to the Conflict was processed graphically using the Wolverine Software Proof graphics animation package. Figure 11 is a Proof screen capture at the time of Conflict start, and Figure 12 is a screen capture at the time of Conflict end.

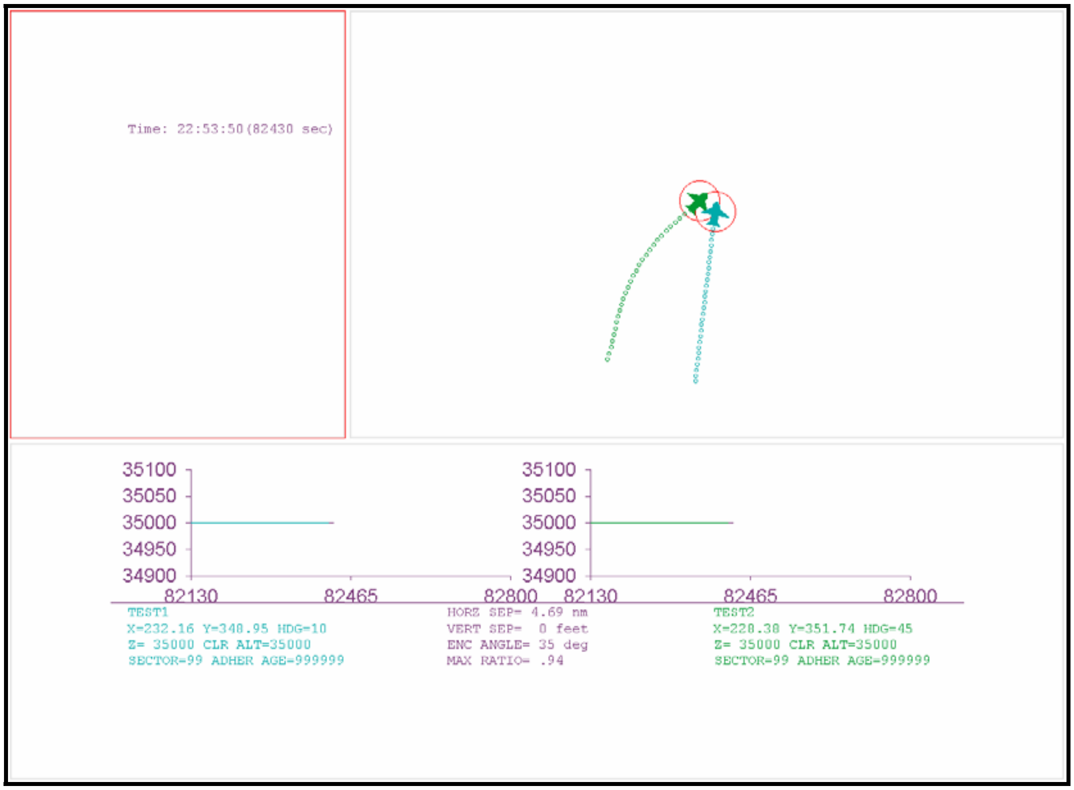

Figure 11: Proof Screen Capture at Start of Conflict

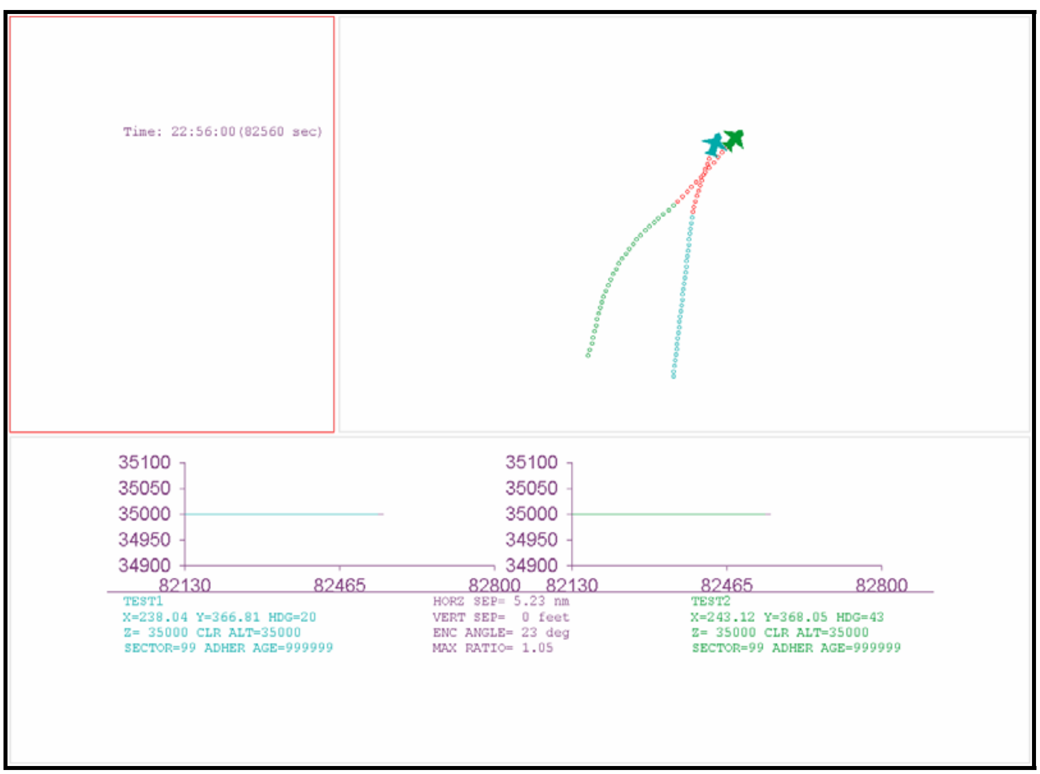

Figure 12: Proof Screen Capture at End of Conflict

3.4.1.3 Analysis

As a result of this conflict, the HCS generated a NS. The first entry in this NS, the ADD alert, was generated at 82357 seconds into the scenario, and represents the earliest notification by the HCS of the pending conflict. The actual start of the conflict was at 82430 seconds into the scenario, so the actual warning time provided was 73 seconds, or 2 seconds less than the specified minimum warning time of 75 seconds.

The track data for the two aircraft involved was examined to determine if the late warning time might be excused. First, it was verified that good track data was present for both aircraft during the time immediately preceding the conflict. Second, an extrapolation test was performed on the track data, as described in Section 3.2.4.3 to check for the presence of an unexpected maneuver that might impact warning time. Starting at a point one sample interval prior to the actual start of the conflict, and working back one sample interval at a time to a point 80 seconds prior to ACST, a straight-line estimate was made of each aircraft's track based upon current speed, altitude, and rate of climb. As shown in Table 4 below, all of the extrapolations predicted a conflict in that minimum-max-ratio was less than 1.0. Given the absence of any warning time reduction factors, this conflict was placed in the MISSED LATE category.

Table 4: Conflict Prediction Results for Flights TEST1 & TEST2

Extrapolation Time (sec)	Min-Max-Ratio	Minimum Horizontal Separation (nm)	Minimum Vertical Separation (ft)	Predicted Conflict Start Time (sec)
82350	0.135	1.838	0	82470
82360	0.002	0.245	0	82460
82370	0.002	0.229	0	82450
82380	0.004	0.332	0	82450
82390	0.005	0.364	0	82440
82400	0.001	0.168	0	82440
82410	0.001	0.178	0	82440
82420	0.009	0.481	0	82430

3.4.2 False Alert Example

This section presents an example of a false alert error. False alerts can occur either when an alert is presented and retracted before a conflict actually starts or when a conflict never occurs and there is no justification for presenting the alert.

3.4.2.1 Flight Description

In this example, the first flight, TEST3, is en route from the Bahamas to Boston, the other flight, TEST4, is en route from Teterboro NJ to West Palm Beach Fl. Two aircraft approach each other on the same route at similar altitudes. A conflict is predicted as they pass each other. At the time of the encounter, Flight TEST3, a Boeing 757-200, is in level cruise at FL390, descending to FL370. Flight TEST4, a Dassault Falcon Mystere, is in level cruise at FL360 and then climbs to FL390. Both aircraft are flying on J174. This is depicted in the following Figure 13.

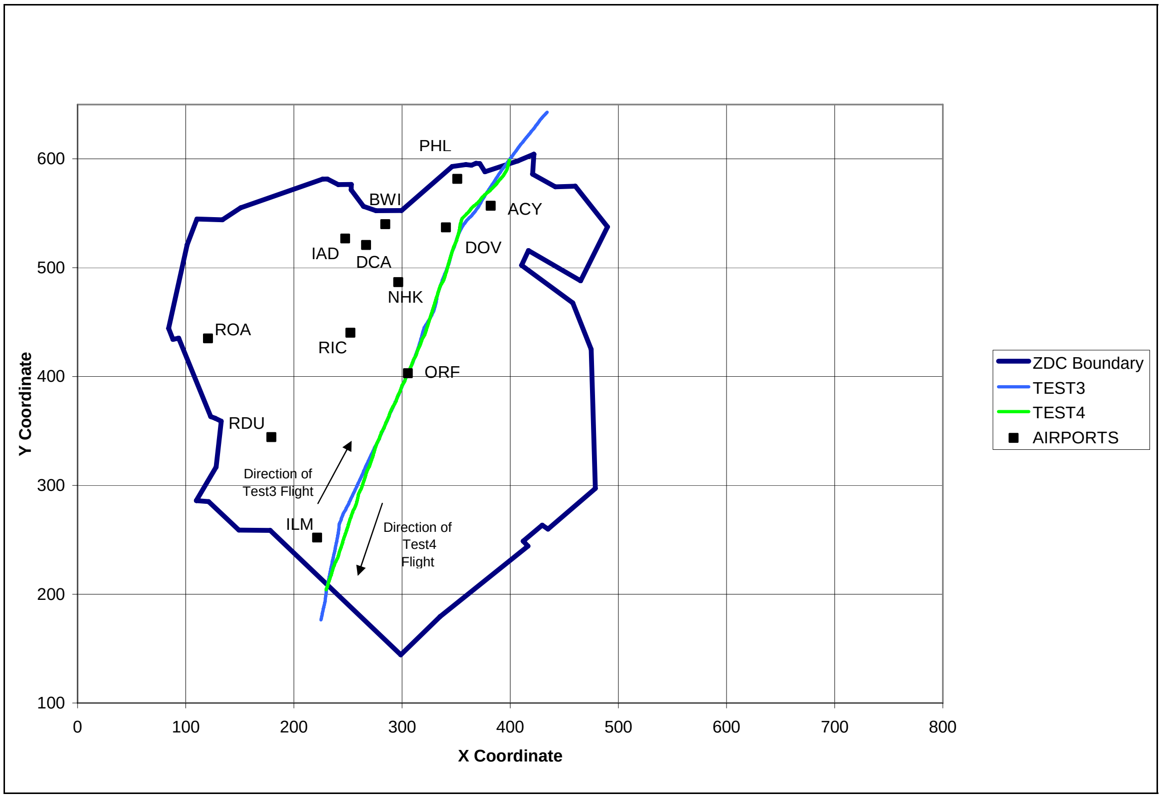

Figure 13: Flight Paths of TEST3 and TEST4

3.4.2.2 Encounter Geometry

A plan view captured from Wolverine Proof Software of the encounter is shown in Figure 14. The aircraft fly past each other, TEST3 flying to the northeast and TEST4 flying to the southwest. Their minimum horizontal separation is 2.57 nautical miles at an altitude separation of 1000 feet at 74570 seconds UTC. TEST3 is in level cruise at FL370 and TEST4 is in level cruise at FL380. The encounter angle is 158 degrees.

Their minimum vertical separation is 0 feet at a horizontal separation of 32.67 nautical miles at 74430 seconds UTC. At this point the aircraft are approaching each other; TEST3 is in level cruise at FL370 having descended from FL390 and TEST4 is climbing through FL370 from FL360 to FL380.

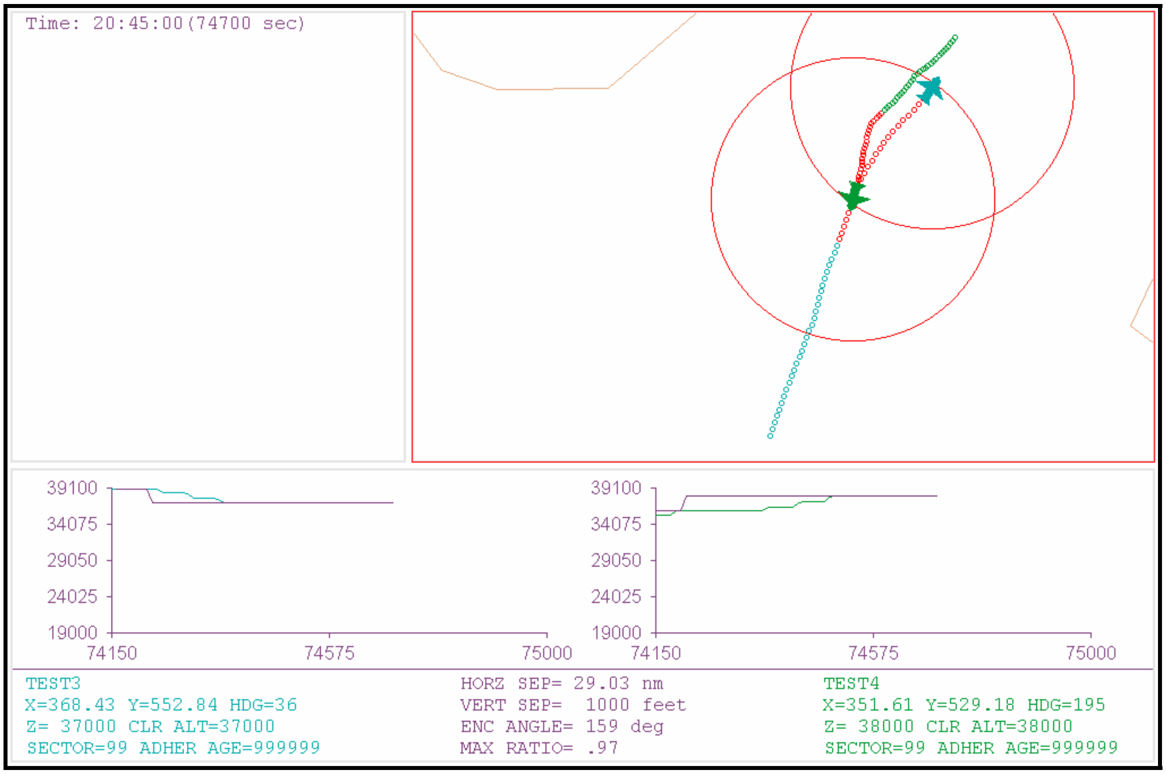

Figure 14: Proof Screen Capture of Encounter between Flights TEST3 & TEST4

3.4.2.3 Analysis

The HCS posts two alerts for this encounter. The first is posted at 74401 and deleted at 74437; the second is posted at 74473 and deleted at 74497. Both predict a conflict starting at 74561.

The first conflict prediction is posted when the aircraft separation is 39.12 nm horizontally and 600 feet vertically. TEST3 is in level cruise at FL370; TEST4 is at FL364 in a step climb from FL360 to FL380. TEST4 is temporarily leveled off at FL364 for 50 seconds.

The second conflict prediction is posted when the aircraft separation is 24.01 nm horizontally and 300 feet vertically. As before TEST3 is in level cruise at FL370; TEST4 is at 37,300 feet in a step climb from FL360 to FL380. TEST4 is temporarily leveled off at FL373 for 40 seconds.

To see if the false alerts should be excused, the analysis program made its own prediction. At the time of the posting of the alerts the (1) location, (2) speed, (3) heading, and (4) rate of climb were determined for both aircraft. Then a straight line flight path prediction was made for each aircraft. The predicted flight paths did not come into conflict for either of the alerts. Therefore the false alerts were not excused. They were labeled as FA_STD1.

4 Summary

This report presents the detailed processing involved in evaluating a tactical conflict probe (CP). In Section 2, the data collection, generation, and validation of the simulation scenarios to drive the CP for evaluation are discussed. In Section 3, the detailed processing of the input or simulated scenario traffic data and the resulting output data (conflict predictions) are presented in detail. This includes detailed flowcharts and descriptions of the many design decisions required for evaluation of the conflict predictions of a CP. It contains definitions of metrics estimating the expected rates of Missed and False Alert events and timeliness performance of the correct predictions. Section 3 also contains two actual flight samples processed using the methods described. These flight samples are taken from simulations performed in the FAA's IIF Laboratory on the HCS's tactical conflict alert function. Complete results of these simulations will be provided in a subsequent report.

5 List of Acronyms/Abbreviations[5]

ACB-550	ERAM & ECG Group, WJHTC, FAA
ACID	Aircraft Identifier (Call Sign)
ACP	Azimuth Change Pulse
ACST	Actual Conflict Start Time
AMTWG	Automation Metrics Test Working Group
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
AWT	Actual Warning Time
CID	Computer Identifier
CMS	Common Message Set
COI	Critical Operational Issue
CP	Conflict Probe
CPAT	Conflict Probe Assessment Team
CPT	Conflict Probe Tool
DS	Display System
ECG	En route Communications Gateway
ERAM	En Route Automation Modernization
E-RIT	En Route Radar Intelligent Tool
FAA	Federal Aviation Administration
FA	False Alert (a.k.a. nuisance alert)
FDP	Flight Data Processing
FL	Flight Level
GH	General Information
GPS	Global Positioning Satellite System
HADDS	Host Air Traffic Management Data Distribution System
GSGT	Graphical Simulation Generation Tool
HCS	Host Computer System
Host	ARTCC main frame computer
IIF	Integration and Interoperability Facility
JMP	JMP
JVN	JVN Communications, Incorporated
MA	Missed Alert
MA_LATE	Missed Alert – Late
MA_STD	Missed Alert – Standard
MWTR	Minimum Warning Time Requirement
Nm	Nautical Miles
NS	Notification Set
ORR	Online Radar Recording
PC	Personal Computer
PCST	Predicted Conflict Start Time
RVSM	Reduced Vertical Separation Minima
SAR	System Analysis Recording
SAS	Statistics Analysis System

[5] The ACB acronyms are now obsolete due to a re-organization in the FAA. However, they are provided here due to the legacy documents referred to in the study.

SDP	Surveillance Data Processing
SDRR	Looped Simulation Drive System Replacement
SQL	Structured Query Language
TPM	Technical Performance Measure
URET	User Request Evaluation Tool
UTC	Coordinated Universal Time (see www.time.gov/about.html)
VA	Valid Alert
VA_LATE	Valid Alert – Late
VA_STD	Valid Alert - Standard
WJHTC	William J. Hughes Technical Center
ZDC	Washington ARTCC

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7 Appendix A

Table 5 listed below presents the full listing of parameters within the three conflict alert processing software programs used in this evaluating the tactical conflict probe in this study. The *AlertTableLoader* is an application that is responsible for parsing the conflict alert records and creating a database of notification sets. *MwtCalculator* application is responsible for calculating the minimum warning time requirement for each conflict event as defined in Section 3.2.4.3. Finally, the *CflPredEval* applies the methodology presented in Section 3.2 to evaluate the Missed and False Alerts.

Table 5: Implementation Software Parameter List

Program Name	Property Parameter Name	Parameter Description
AlertTableLoader	delTimeThres	This parameter to determine if a notification set should be completed with "DEL".
CflPredEval	adherAgeReq	Mostly use 0, or 10 and others. This parameter will decide if MA_LATE or MA_LATE_DISCARD for a conflict pair matched to a notification set
CflPredEval	adherSource	Use CP for C_CP_ADHER_AGE and TP for C_TP_ADHER_AGE from M_CFL_LIST table adherAge default set to 999999 so that if processAdherAgeFlag set to false program only use 999999.
CflPredEval	faNotrkDiscard2Flag	false or true; *This flag and associated function is currently not utilized in the software.*
CflPredEval	processAdherAgeFlag	false or true. If true use the C_CP_ADHER_AGE or C_TP_ADHER_AGE from M_CFL_LIST based on adherSource (CP or TP); if false use 999999 only; *This flag and associated function is currently not utilized in the software.*
CflPredEval	para4	Default 10 or 40, 150 etc. used for MA_STD_A during processA. This parameter is to be used to find a gap for a popup conflict during processA.
CflPredEval	Para5	Default 40 or others. The para5 was used to decide MA_DISCARD or MA_STD_B. It was used in a select statement from safety_alert table during processA.
CflPredEval	timeP1	Default 20. The parameter was used for FA_EVENT_DISCARD_A or FA_STD2_A or FA_STD2_B or FA_EVENT_DISCARD_B during extrapolating a test track.
CflPredEval	endAheadTime	Default 150. The parameter was used to extrapolate a test track as time range for it.
MwtCalculator	mergeThresValue	Default 0; The value was applied to the EventList constractor. It was used to test if these was a gap in EvenList

MwtCalculator	gapThresValue	Default 10; The value was applied to the EventList constractor.
MwtCalculator	numOfBustPts	The value was applied to the EventList constractor; comparing with bustEventCount.
MwtCalculator	deltaTimePara1	Default 40; the parameter was used to find start or re-start of the track with its latest gap after ending loop2 within the loop of mcfl_list.
MwtCalculator	baseWarningTime	The default value is 80. The value will be used to backward to the time point by that the track would be extrapolated from the actual conflict start time.
MwtCalculator	timeInc	The default value is 10. The value will be used as time step when extrapolating a test track.
MwtCalculator	endAheadTime	The default value is 150. The value is used to as the max track points to extrapolate.
MwtCalculator	normMwt	This is the norm Minimum Warning time. The default will be 75.